THE UNIVERSITY OF ALBERTA

BIO-OXIDATION RATES UNDER ICE COVER IN THE NORTH SASKATCHEWAN RIVER

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled BIO-OXIDATION RATES UNDER ICE COVER IN THE NORTH SASKATCHEWAN RIVER, submitted by ROBERT DOUGLAS CAMERON in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE

ABSTRACT

BIO-OXIDATION RATES UNDER ICE COVER IN THE NORTH SASKATCHEWAN RIVER

The results of a field study of factors affecting bio-oxidation rates in an ice covered river under low flow conditions are presented.

River velocity measurements were made using Rhodamine B dye as a tracer material. For a river discharge of 3000 c. f. s. under ice cover, an average value of 88 for K in the equation $V = KS^{\frac{1}{2}}$ was found. Mean river velocities under ice cover ranged from 1.14 to 2.04 ft./sec. In open water a velocity of 1.86 ft./ sec. was measured for a river slope of 2.87×10^{-4} ft./ft. and a discharge of 3080 c. f. s.

Limestone sampling baskets placed in the river at three locations showed that slimes and sludges were progressively building up on the river bottom immediately downstream from Edmonton. This build up, approximately 1/8 to 1/2 inch thick, exerted no measurable oxygen demand on the waters above. Increased river velocities in the spring under open water conditions scoured the slime layer and temporarily raised average B. O. D. values from 6 to 10 mg./l. immediately downstream from Edmonton and from 1 to 10 mg./l., 175 miles downstream.

Measurements of B. O. D., dissolved oxygen and C. O. D. were taken on different slugs of water as they proceeded down the river. From the data obtained, it is postulated that in the river reaches immediately downstream from Edmonton, B. O. D. reduction primarily takes place due to adsorption and settlement of organic material.

In the river reach from Edmonton to thirty miles downstream, no straightforward relationship existed between B. O. D. reduction and dissolved oxygen uptake. In the reaches further downstream, the dissolved oxygen depletion rate became relatively constant. An equation defining the dissolved oxygen deficit is formulated for the river discharges and B. O. D. loadings which occurred during the study. This equation is of the general form, $D = D_o + K \log \frac{t_2}{t_1}$ where D and D_o are the dissolved oxygen deficits in mg./l. at time t_2 and t_1 days respectively downstream from Edmonton.

Dissolved oxygen levels upstream from Edmonton varied between 11.0 and 13.7 mg./l. during the winter, while 212 miles downstream values ranged from 5.9 to 7.7 mg./l. In this reach, river B. O. D. was reduced by 4 to 5 mg./l. Fifty five to seventy three per cent of this reduction took place within the first thirty miles downstream from Edmonton.

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CHAPTER I

INTRODUCTION

1. The North Saskatchewan River

The North Saskatchewan River holds an unique position among major rivers on the North American continent in that, as a major source of water supply and as a receiver of municipal and industrial waste waters, it is completely frozen over during the winter for periods averaging five months. During this period of ice cover, minimum discharges also occur in the river.

2. Dissolved Oxygen

A measure, not only of the "cleanness" of a river, but also of the capacity of a river to absorb pollutional loads placed upon it, is the amount of dissolved oxygen (D. O.) which the river contains. The absence of dissolved oxygen, combined with industrial and municipal pollution, in a river such as the North Saskatchewan, produces a septic condition which not only prohibits the presence of fish life but also creates a taste and odor problem for downstream users of the river.

During open water periods, dissolved oxygen levels in the river drop in the area downstream from the major sources of pollution; but, due to reaeration from the atmosphere the drop is slight and satisfactory dissolved oxygen levels are readily maintained. Under ice cover, no reaeration is

possible so that, in order to avoid septic conditions in the river, either total pollutional loadings to the river must be carefully controlled, waste waters must be given better treatment, waste waters must be stored during the winter and released during high summer river flows in open water, or reaeration must be provided in the river by mechanical means.

3. Previous Problems And Control

During the winter of 1955-56, strong septic odors were found in the river at Duvernay, Lindbergh and Lloydminster. It was then found that dissolved oxygen levels had been completely depleted in the river sixty miles downstream from Edmonton. This led to an attempt to artificially aerate the river (Alberta Department of Public Health, 1956). With the cooperation of the City of Edmonton and the Provincial Department of Public Works, the Sanitary Engineering Division of the Department of Public Health set up an air compressor system near Redwater, Alberta in an attempt to artificially raise the dissolved oxygen levels in the river. Severe cold weather, drifting snow and several mechanical difficulties prevented the continuous operation of the system from starting until March 10, 1956. The operation continued for eighteen days, at which time, melting conditions made it necessary to remove equipment from the ice. During the continuous operation, a rise of only 0.25 parts per million (p. p. m.) in dissolved oxygen level was observed immediately downstream from the aeration system. No increase in dissolved oxygen was observed further downstream.

Since the winter of 1955-56, improved dissolved oxygen levels have been maintained in the river (FIGURE 1). This has been brought about

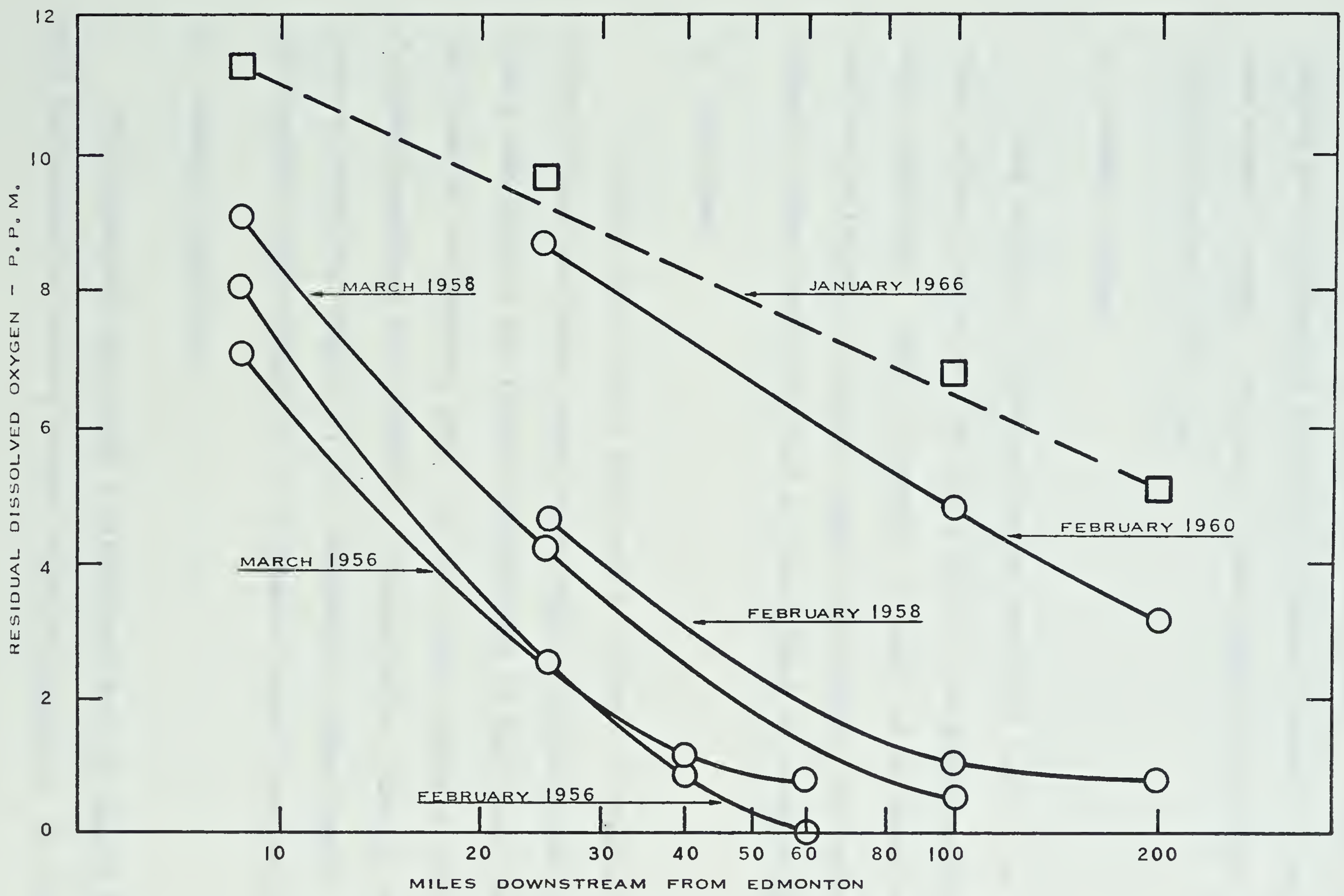

FIGURE I

RESIDUAL DISSOLVED OXYGEN
NORTH SASKATCHEWAN RIVER

DATA FROM THE ALBERTA GOVERNMENT SANITARY
ENGINEERING DIVISION

by the start up, in the fall of 1956, of the primary treatment section of a new main sewage treatment plant, augmented in 1957 by the use of secondary treatment facilities at this plant. In 1965, sewage lagoons were constructed for winter storage of packing plant wastes and some domestic sewage. The use of these lagoons has further reduced winter loadings imposed on the river.

4. Present Problem

Many studies of dissolved oxygen have been carried out on rivers whose critical period of low flow occurs in the summer months under open water conditions. There is, however, a dearth of information in North American writings on dissolved oxygen relationships and rates of bio-oxidation under conditions such as those found in the North Saskatchewan.

5. Study Goal

The prime goal of this study was an attempt to forecast the dissolved oxygen level which would occur many miles downstream from Edmonton, from a knowledge of the factors contributing to the demand for oxygen in the river in the Edmonton area. In this study, slugs of water were followed downstream from Edmonton to Lloydminster, Alberta, with measurements of dissolved oxygen (D. O.), biochemical oxygen demand (B. O. D.) and chemical oxygen demand (C. O. D.) being taken at suitable locations.

6. Research Limitations

The parameters which play a significant role in oxygen demand are many and varied and largely beyond individual control. To formulate an

expression for the oxygen relationships in the river under ice cover would require a great number of runs down the river under varying conditions of river flow and under varying conditions of chemical and biochemical loadings from the many waste water sources in the Edmonton area. Due to the time required for each run and also to the many and varied problems which arose during the course of testing, the number of test runs was very limited. It is felt, however, that the present study will be of benefit and will provide a suitable base from which further research in this field may be carried forward.

CHAPTER II

DESCRIPTION OF STUDY AREA

1. General Description

The North Saskatchewan river rises in the Rocky Mountains near the Continental Divide (FIGURE 2) some two hundred miles south west of Edmonton. It flows in an easterly direction through Alberta into Saskatchewan to a point some thirty miles east of Prince Albert, Saskatchewan, where it is joined by the South Saskatchewan River (FIGURE 3). From this point, it flows, as the Saskatchewan River, into Lake Winnipeg in the Province of Manitoba. The waters of Lake Winnipeg are then carried by the Nelson River into Hudson Bay. In Alberta, 36,000 square miles or 14.1% of the total area of the province are drained by the North Saskatchewan River (Thomas, 1956).

The river rises at an elevation some 5000 feet above sea level and flows, with diminishing slope, approximately 330 miles to Edmonton, at which point its elevation is 2010.6 feet above geodetic datum (FIGURE 4). From Edmonton to the Alberta-Saskatchewan border the river flows a distance of 210.3 miles and falls to an elevation of 1639 feet. This latter section is the area in which the present studies were conducted.

Below Edmonton, the major tributaries to the river in Alberta are the Sturgeon, Redwater and Vermilion Rivers. These rivers are virtually frozen solid during the winter months and therefore make essentially no contribution to the flow of the North Saskatchewan.

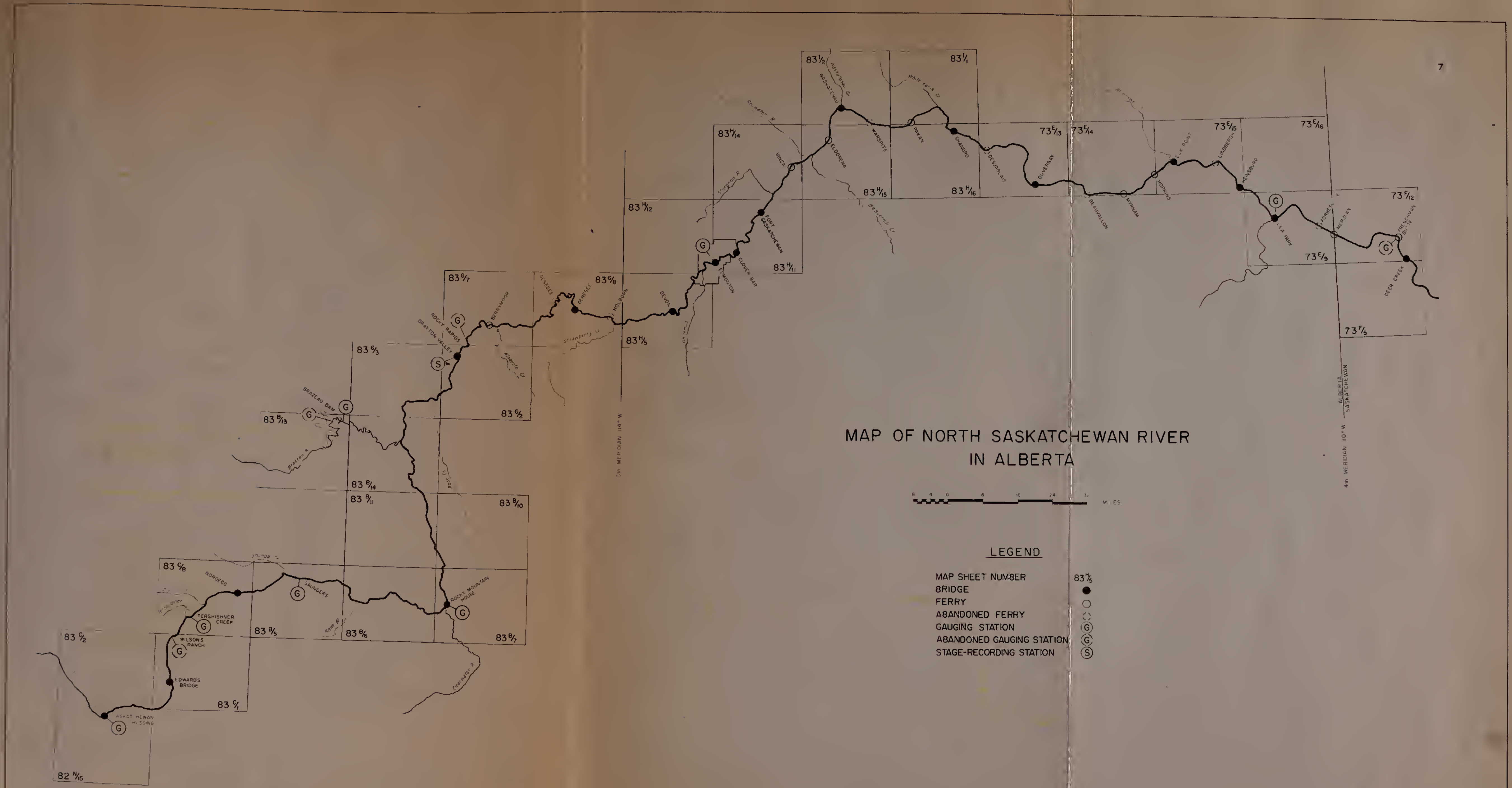
MAP OF NORTH SASKATCHEWAN RIVER
IN ALBERTA
MILES
LEGEND
MAP SHEET NUMBER 83 H/5
BRIDGE
FERRY
ABANDONED FERRY
GAUGING STATION
ABANDONED GAUGING STATION
STAGE-RECORDING STATION
82 N/15
83 C/2
83 C/1
83 C/8
83 B/5
83 B/6
83 B/7
83 B/10
83 B/11
83 B/14
83 B/13
83 G/2
83 G/3
83 G/7
83 G/8
83 H/5
83 H/12
83 H/11
83 H/14
83 H/15
83 H/16
83 I/2
83 I/1
73 E/13
73 E/14
73 E/15
73 E/16
73 E/9
73 F/12
73 F/5
EDWARD'S BRIDGE
WILSONS RANCH
TERSHISHNER CREEK
NORDEGG
SAUNDERS
ROCKY MOUNTAIN HOUSE
BRAZEAU DAM
Brazeau R.
Ram R.
Clearwater R.
DRAYTON VALLEY
ROCKY RAPIDS
BERRYMOOR
GENESEE
Strawberry Cr.
HOLBORN
DEVON
5th MERIDIAN 114° W
EDMONTON
CLOVER BAR
FORT SASKATCHEWAN
Sturgeon R.
VINCA
ELDORENA
SASKATCHEWAN
WARSPITE
PAKAN
SHANDRO
DESJARLAIS
DUVERNAY
BRUSHVALLON
MYRNAM
HOPKINS
ELK POINT
LINDBERGH
HEINSBURG
LEA PARK
FORBES
MERIDIAN
FRENCHMAN BUTTE
DEER CREEK
4th MERIDIAN 110° W
ALBERTA
SASKATCHEWAN

FIGURE 2

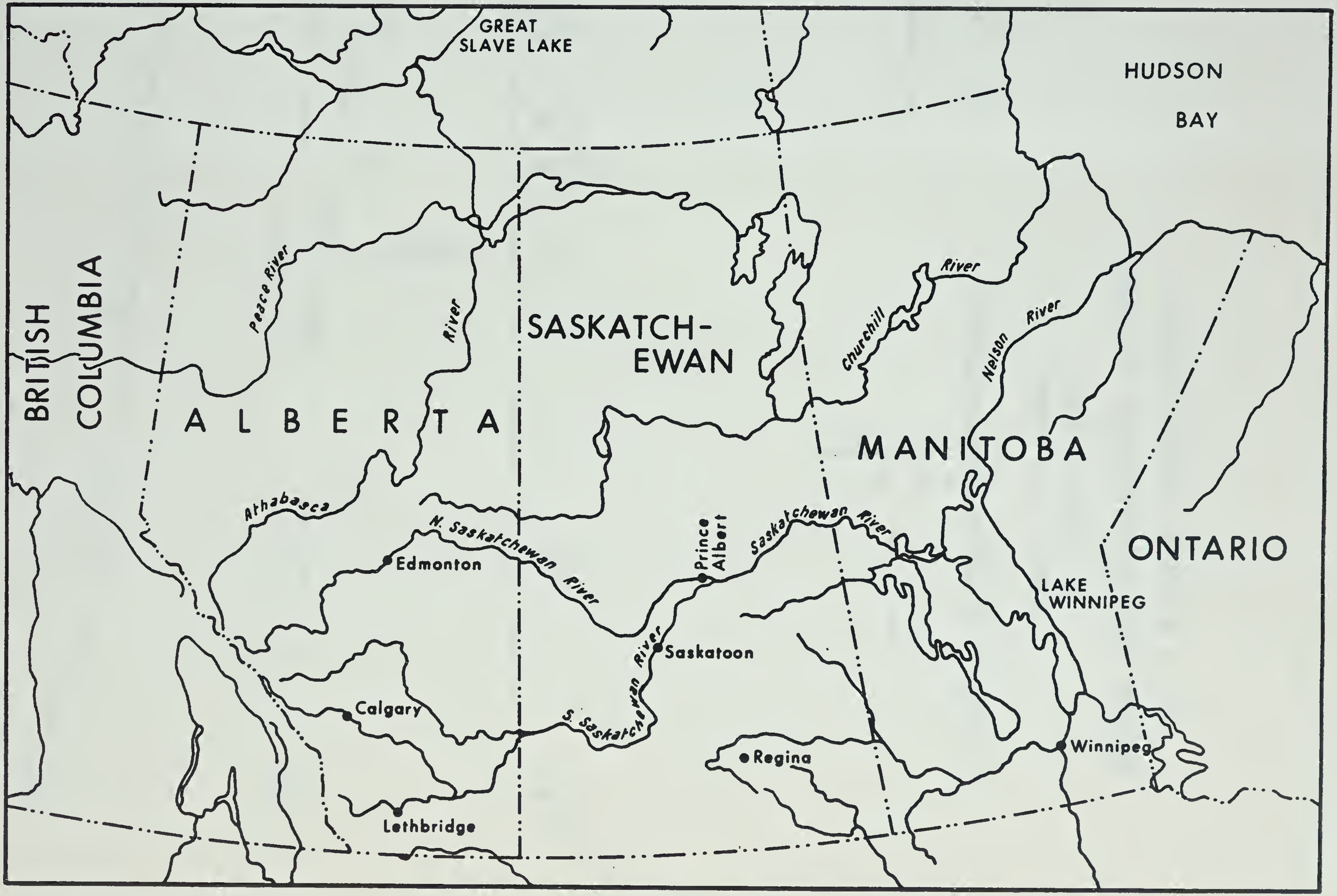

FIGURE 3 SASKATCHEWAN RIVER IN WESTERN CANADA

LONGITUDINAL PROFILE OF NORTH SASKATCHEWAN RIVER IN ALBERTA

Research Council of Alberta

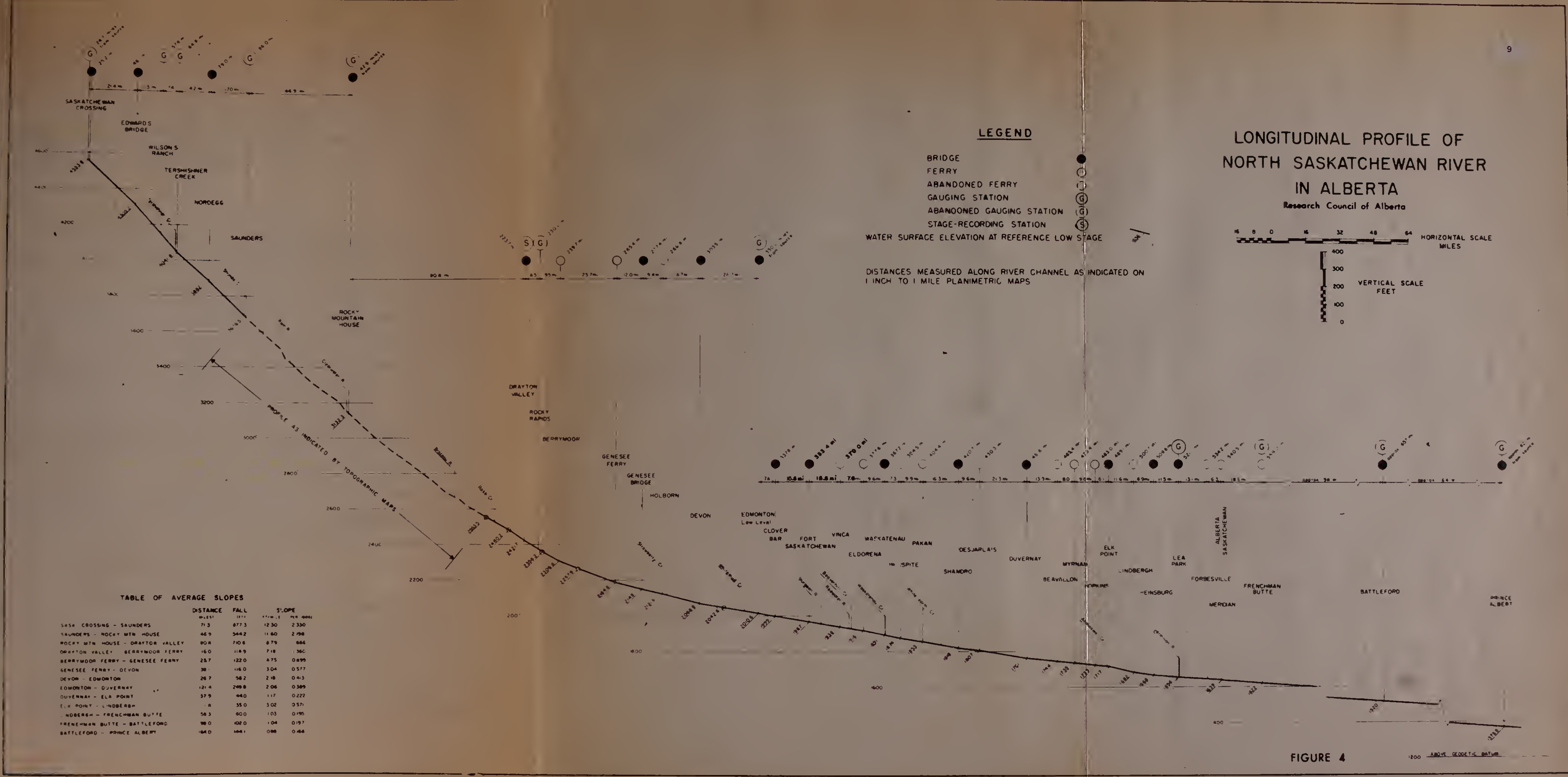

FIGURE 4

TABLE OF AVERAGE SLOPES

	DISTANCE (MILES)	FALL (FT)	SLOPE (FT/MILE)	SLOPE (PER 1000)
SASK CROSSING - SAUNDERS	71.3	877.3	12.30	2.330
SAUNDERS - ROCKY MTN HOUSE	46.9	544.2	11.60	2.198
ROCKY MTN HOUSE - DRAYTON VALLEY	80.8	710.6	8.79	664
DRAYTON VALLEY - BERRYMOOR FERRY	16.0	114.9	7.18	1.360
BERRYMOOR FERRY - GENESEE FERRY	25.7	122.0	4.75	0.899
GENESEE FERRY - DEVON	38.1	116.0	3.04	0.577
DEVON - EDMONTON	26.7	58.2	2.18	0.413
EDMONTON - DUVERNAY	121.4	249.8	2.06	0.389
DUVERNAY - ELK POINT	37.9	44.0	1.17	0.222
ELK POINT - LINDBERGH	[illegible]	35.0	3.02	0.571
LINDBERGH - FRENCHMAN BUTTE	58.3	60.0	1.03	0.195
FRENCHMAN BUTTE - BATTLEFORD	98.0	102.0	1.04	0.197
BATTLEFORD - PRINCE ALBERT	164.0	144.1	0.88	0.166

2. Climate

Central Alberta, through which the river flows, is in the cold temperate region of North America. Edmonton's climate is summarized in TABLE I (Kendrew & Currie 1955).

3. River Flow

The North Saskatchewan River is characterized not only by its relatively long period of ice cover but also by the wide variation between maximum and minimum daily discharges. TABLE II illustrates this broad variation in flow. From TABLE II it can be seen that maximum flows occur most frequently in June and July with very few maximums occurring in April, May, August and September. The incidence of maximum flow is caused by either heavy rainfall, a high rate of snowmelt in the mountains or a combination of both of these factors. June and July are the months in which Edmonton receives its greatest amounts of precipitation and are also the months in which daily mean temperatures are reaching their peak. An examination of the discharge hydrographs for the North Saskatchewan River at Edmonton shows a general tendency to two peaks each year; a spring flood in April or May and a summer flood in June or July; but not all years necessarily show this pattern.

Prior to 1963, winter flows in the river were primarily due to base flow from groundwater storage. Since 1963, base flow has been augmented in the winter months by releases from the storage capacity of the Brazeau Dam (FIGURE 2 & TABLE II). This dam, located on one of the major tributaries to the North Saskatchewan River, was principally developed as a

TABLE I

CLIMATOLOGICAL SUMMARY FOR EDMONTON, ALBERTA

Highest recorded temperature	99°F.
Lowest recorded temperature	-57°F.
Mean total annual precipitation	18.0 inches
Mean total annual snowfall	51 inches
Mean annual number of days with frost	195
Daily mean air temperatures	
October	41°F.
November	24°F.
December	13°F.
January	6°F.
February	11°F.
March	23°F.
April	40°F.
Mean of the year	37°F.

TABLE II

NORTH SASKATCHEWAN RIVER DISCHARGES

(Compiled by Professor J. P. Verschuren. Information from the Federal Water Resources Branch.)

Water year	Maximum instantaneous discharge c. f. s.	Maximum daily discharge c. f. s.	Date of maximum daily discharge	Minimum daily discharge c. f. s.	Date of minimum daily discharge
1911		51442	Jul. 3		
1912		74100	Jul. 10	1062	Mar. 25
1913		32600	Aug. 15	1210	9 d. Ma-Ap.
1914		61740	Jun. 9	650	Dec. 24-26
1915	204500	164000	Jun. 29	700	Dec. 15
1916	61600	58800	Jun. 22	950	Mar. 4
1917		65597	May 18	1100	Feb. 22
1918		35347	Jun. 16	960	Dec.12-Feb.20
1919		19885	Jun. 24	688	Mar. 4
1920		57220	May 10	895	Dec. 4
1921	27400	24888	May 23	800	Dec. 23
1922	28600	25760	Aug. 18	380	Nov. 25
1923	99600	84100	Jun. 25	540	Dec.12,Jan.11
1924	27600	27500	Jul. 5-6	760	Jan. 24
1925	77000	75800	Aug. 18	538	Feb. 26
1926		58700	Sept. 4	1140	Jan. 19-31
1927		40400	Jun. 29	1290	Dec. 16-18
1928		61200	Jul. 7	1330	Nov. 13
1929		38100	Jun. 5	965	Jan.19-Feb.2
1930	23900	23700	Jul. 17	952	Jan.16-Feb.14
1931		39200	Jul. 2	700	Mar. 16
1932		66000	Jun. 4	865	Mar. 14
1933		34400	Jun. 19	796	Dec. 13
1934		28100	Jun. 1	900	Mar. 2
1935		46300	Jul. 11	406	Jan. 3
1936		40400	Apr. 19	485	Apr. 4
1937		31500	Jul. 17	480	Dec.23,Jan.3
1938		40000	Jul. 4	682	Feb. 4, 14
1939		30200	Jun. 28	1030	Mar. 3-5
1940		35700	Apr. 18	220	Jan. 1

TABLE II (cont.).

Water Year	Maximum instantaneous discharge c. f. s.	Maximum daily discharge c. f. s.	Date of maximum daily discharge	Minimum daily discharge c. f. s.	Date of minimum daily discharge
1941		26720	Jun. 28	548	Nov. 17
1942	43960	42250	Jul. 14	583	Nov. 26
1943		44020	Apr. 12	1080	Feb. 10-13
1944	125900	121970	Jun. 16	551	Nov. 22
1945	25060	24300	Jun. 1	724	Nov. 30
1946		44730	Jun. 24	1300	Feb. 8
1947		28600	Jun. 13	602	Nov. 27
1948	66620	65440	May 25	1140	Feb. 12
1949		32680	Jul. 22	730	Dec. 14
1950	53720	50330	Jun. 17	430	Dec. 13
1951	40980	39020	May 3	624	Nov. 25
1952	132000	125000	Jun. 25	1030	Dec. 23
1953	45800	44900	Jun. 5	652	Nov. 29
1954	118400	106600	Jun. 8	833	Apr. 8
1955	32020	30380	Jun. 15	1040	Jan. 5
1956	26600	25460	Jun. 7	580	Nov. 20
1957	23380	21780	Jun. 11	506	Dec. 13
1958	52130	49890	Jul. 1	1180	Jan. 7-8
1959	51740	46140	Jun. 29	598	Dec. 14
1960	38810	36830	Jul. 3	640	Nov. 20
1961	30100	27210	Jul. 31	700	Nov. 30
1962	28500	27000	Aug. 6	575	Nov. 28
1963	39900	37100	Jul. 18	1330	Jan. 2
1964	49700	47600	Jun. 21	1350	Nov. 25
1965	95300	91600	Jun. 29	1070	Dec. 1
1966		57800	Jul. 6	2280	Dec. 15
1967				1500	Dec. 7

source of hydroelectric power. As stated by Reid & Brittain (1962), it will also serve to reduce spring and summer flood peaks with its storage capacity and also provide increased flow to the North Saskatchewan River during the winter low flow periods. It is expected that, with full development of the Brazeau Dam, measured discharges in the North Saskatchewan will not fall below 1500 c. f. s. The river discharges at Edmonton during several winter periods, as shown in FIGURE 5, demonstrate the increased winter flow in the past few years.

4. Ice Cover

As previously mentioned, the river surface is completely frozen over during the winter for periods of up to six months. A frequency distribution of lengths of periods of ice cover is shown in FIGURE 6. Within the City of Edmonton itself, warm water from the city power plant as well as effluents from the city sewage treatment plants and from the industrial plants in the greater Edmonton area serve to keep the river open from the city power plant to the vicinity of the Clover Bar bridge (FIGURES 7 & 8). The amount of open water varies from day to day depending upon the air temperature and waste & cooling water discharge temperatures. During most of the winter of 1966-67, which was characterized by a two week period of well below normal temperatures in early December, the river was observed to remain fairly open with narrow shelves of ice (25 to 50 feet wide) extending from both banks, from the power plant to just below the Edmonton Main Sewage Treatment Plant. Below this area however, the open water channel narrowed down to between 25 and 100 feet wide and finally was generally covered over just downstream

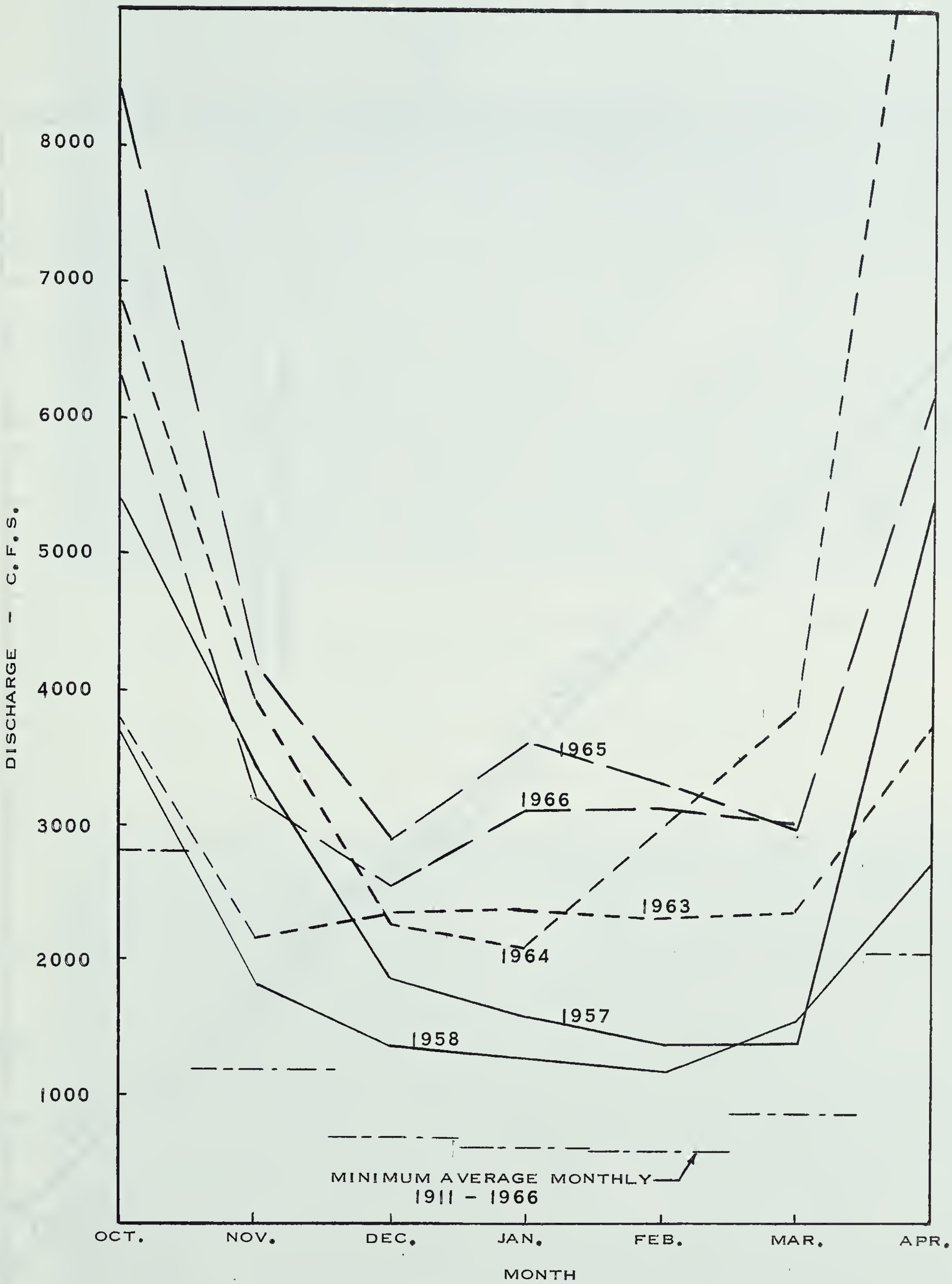

FIGURE 5 AVERAGE MONTHLY FLOW
NORTH SASKATCHEWAN RIVER
DATA FROM FEDERAL DEPARTMENT OF WATER RESOURCES

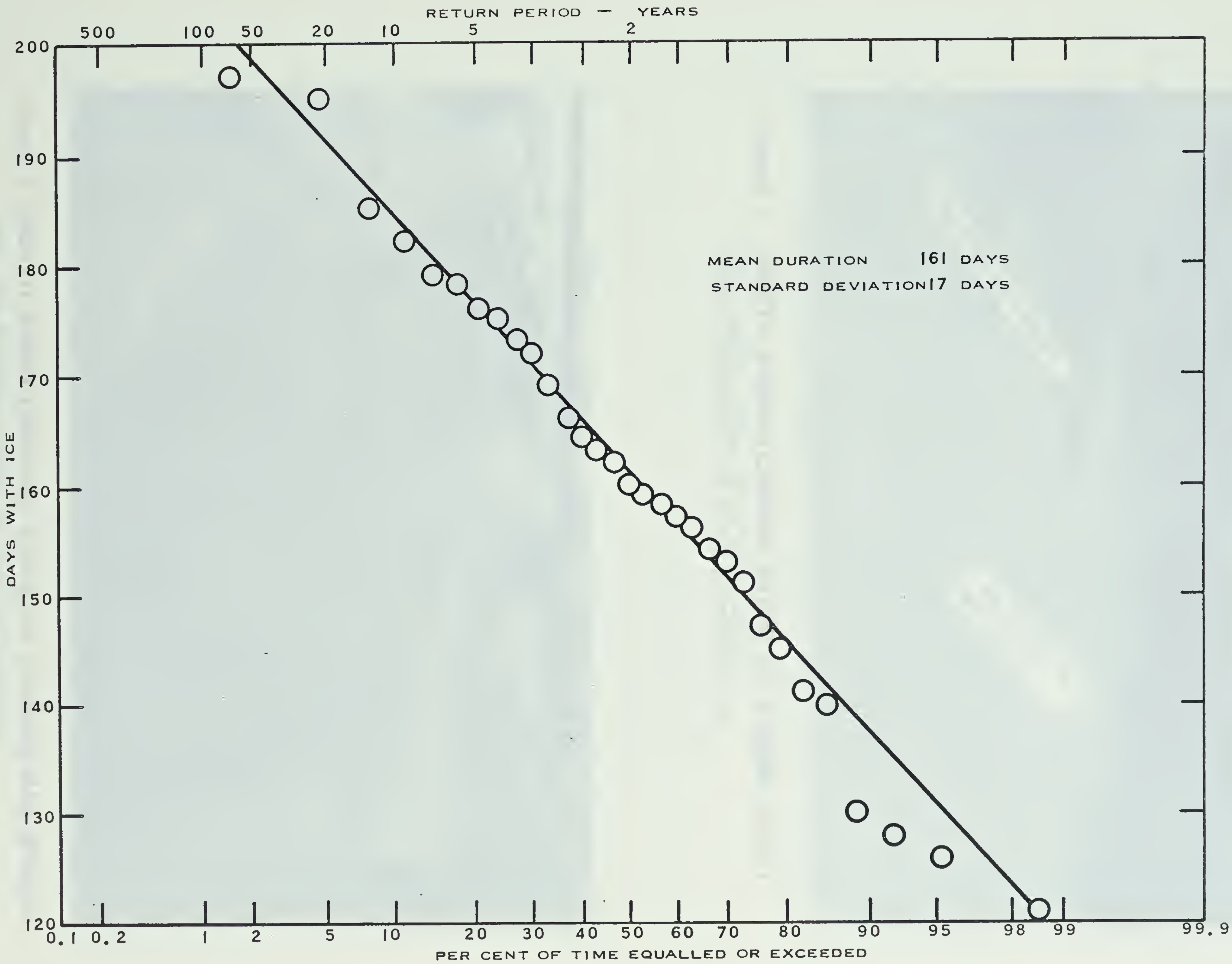

FIGURE 6 DURATION OF ICE – NORTH SASKATCHEWAN RIVER 1915 – 1965

FIGURE 7 NORTH SASKATCHEWAN RIVER AT POWER PLANT

RAW WATER INTAKE IS IN OPEN WATER.
WHITE FOREGROUND IS SNOW ON TOP OF ICE.

FIGURE 8 NORTH SASKATCHEWAN RIVER AT CLOVER BAR BRIDGE

NOTE ICE SHELVES PROJECTING FROM BOTH BANKS.

of the Clover Bar bridge. The changing location of ice cover is evidenced by observations on January 13 and 18, 1967. On January 13, open water was found at the sampling point $5\frac{1}{2}$ miles downstream from the Clover Bar bridge. On January 18, the river at the Clover Bar bridge was completely frozen over.

5. River Uses

The North Saskatchewan River is used as a major source of water supply and as a receiver of wastes not only by the City of Edmonton and its associated industrial plants but also by towns and industries both upstream and downstream from Edmonton. TABLE III summarizes the major users of the river.

During the summer months, effluents from sewage oxidation ponds of some municipalities near the river, downstream from Edmonton, reach the river during periods of high flows but in winter time these drainage courses are frozen.

Domestic wastes from Devon and Rocky Mountain House are discharged into the river above Edmonton. However, as Paterson (1966) has stated, these create no observable effect on the river immediately upstream of Edmonton's raw water intake. Small values of biochemical oxygen demand (B. O. D.) were found at this point, illustrating that the river itself has a B. O. D. of about 0.5 p. p. m.

Snow containing sand and road salts from city streets is dumped on the river ice by the City of Edmonton (FIGURE 9) but has no effect on

TABLE III

MAJOR USERS OF THE NORTH SASKATCHEWAN RIVER

(From information supplied by the Alberta Department of Public Health)

User	Purpose of Use
Town of Rocky Mountain House	Water supply and sewage disposal.
Town of Devon	Water supply and sewage disposal.
City of Edmonton	Water supply and sewage disposal. Snow dumping. Cooling water for power plant.
Canadian Industries Ltd. Building Products Ltd.	Waste water disposal.
Imperial Oil Ltd. McColl Frontenac Oil Co. British American Oil Co. Chemcell (1963) Ltd.	Waste water disposal and water supply
County of Strathcona	Municipal Sewage disposal.
City of Edmonton Sewage Lagoons	Waste storage for disposal in summer months.
Town of Fort Saskatchewan	Municipal sewage disposal
Sherritt Gordon Mines Ltd. Fort Saskatchewan Dow Chemical Ltd. Fort Saskatchewan	Water supply and waste water disposal.
Western Chemicals Ltd. - Duvernay	Water supply and waste water disposal.
Canadian Salt Co. Ltd. - Lindbergh	Water supply & waste water disposal.
City of Battleford - Saskatchewan	Water supply and sewage disposal.
City of North Battleford - Sask.	Water supply and sewage disposal.
City of Prince Albert, Saskatchewan	Water supply and sewage disposal.

FIGURE 9 SNOW DUMP ON THE NORTH SASKATCHEWAN RIVER

WHITE FOREGROUND IS SNOW ON RIVER ICE.
DARK CENTRAL AREA IS SNOW AND SAND MIXTURE.
NOTE BULLDOZER IN CENTER OF PICTURE.

FIGURE 10 MAIN SEWAGE TREATMENT PLANT EFFLUENT

NOTE WATER VAPOR DUE TO COLD AIR TEMPERATURE.

the river during the winter months. During spring break-up, a certain amount of suspended material and road salts enter the river from this source but with the increased river flow and velocity corresponding with spring break-up, the concentrations of salt and sand in the river from this source are insignificant.

The major sources of wastes flowing to the river are the two City of Edmonton sewage treatment plants. The smaller of these is the plant known as the Number three sewage treatment plant (#3 STP) which is located near the 105th Street Bridge and just downstream and across the river from the city raw water intakes (FIGURE 7). This plant serves a purely residential area on the south side of the river and operates as a primary treatment plant only. The main sewage treatment plant (MSTP) (FIGURE 10) is located near 50th Street on the south bank of the river. During high summer river flows the plant operates as a primary treatment plant only. During low flows and under ice cover, the primary treatment is augmented with secondary activated sludge treatment. Secondary treatment is usually started the first week in November and operation ceases toward the middle of May. A summary of effluent characteristics of these two plants is given in TABLE IV.

The City of Edmonton has recently constructed a series of sewage lagoons which are located in an old gravel pit in the far north east corner of the city. These sewage lagoons receive industrial wastes from several meat packing plants in the north east area of the city, the domestic wastes from the Beverly subdivision in the far north east section of the city and domestic wastes from Sherwood Park, a hamlet in the County of

TABLE IV

EFFLUENT CHARACTERISTICS OF EDMONTON SEWAGE TREATMENT PLANTS
-1966-

(Information Supplied by the City of Edmonton
Engineering Department)

Main Sewage Treatment Plant

	Month	Flow MIGD	20°C. 5 day BOD lb./day	Suspended Solids lb./day	Phenols ppb	Grease ppm	Coliforms per 100 ml. $x10^{-6}$
	Jan.	22.49	11800	14400	12	2	16.3
	Feb.	22.85	12100	14100	26	16	1.12
	Mar.	29.22	24800	45300	22	23	1.92
	Apr.	29.38	16500	33200	14	15	0.51
(a)	May	24.68	33400	37300	-	19	0.7
	June	26.19	50500	55300	120	59	8.2
	July	26.08	54000	56600	73	77	-
	Aug.	32.82	62700	79600	69	68	6.2
	Sept.	27.02	44200	45700	91	68	23
	Oct.	23.49	46700	42600	142	108	7.9
(b)	Nov.	22.58	22000	25000	74	30	1.1
	Dec.	22.64	6200	12800	26	41	1.26

(a) Secondary treatment terminated May 19, 1966.
(b) Secondary treatment started Nov. 7, 1966.

TABLE IV (Cont.)

#3 Sewage Treatment Plant

Month	Flow MIGD	$20^{o}C$. 5 day BOD lb./day	Suspended Solids lb./day	Phenols ppb	Grease ppm	Coliforms per 100 ml. x 10^{-6}
Jan.	2.17	2500	1600	32	30	13.3
Feb.	2.54	4100	2700	122	44	17
Mar.	2.68	3700	2700	72	42	7.6
Apr.	3.38	3800	3300	65	28	6.3
May	2.77	3300	2900	37	31	13
June	2.00	2000	1900	41	62	19
July	2.56	2600	2500	38	55	-
Aug.	2.54	2500	2500	37	46	15.7
Sept.	2.81	2200	2400	23	28	12
Oct.	2.75	4200	5600	72	57	36
Nov.	2.50	3200	2500	86	39	21.1
Dec.	2.21	2600	2300	100	51	19.6

Strathcona immediately east of the city. These lagoons are used to store wastes during the winter period of low river flow and are drained to the river each summer during periods of high river discharge. The use of these lagoons has greatly reduced the loadings imposed on the main sewage treatment plant (TABLE V).

In recent years the North Saskatchewan river has been used more and more frequently by pleasure craft and in the summer of 1964 two commercial excursion boat establishments were inaugurated.

This increased use of the North Saskatchewan river by municipalities, industries and private citizens has necessitated an expanded program of pollution control which, it is hoped, will maintain the river in a suitable condition for use by future generations.

TABLE V

EDMONTON MAIN SEWAGE TREATMENT PLANT

AVERAGE INFLUENT ANALYSIS

(Information supplied by the City of Edmonton Engineering Department)

	Prior to use of lagoons	After use of lagoons	
	January 1965	January 1966	January 1967
Flow - M. I. G. P. D.	23.60	22.49	22.62
5 day 20°C. BOD - ppm	473	349	280
Suspended solids - ppm	585	409	341
Greases - ppm	223	120	141

CHAPTER III

THEORY OF RATES OF BIO-OXIDATION AND THE DISSOLVED OXYGEN PROFILE

1. Introduction

An understanding of the dissolved oxygen profile and of rates of bio-oxidation must include an awareness of several parameters other than dissolved oxygen. The important parameters which have been included in the present study are, the B. O. D. and C. O. D. of the river and of the wastes entering the river; a study of the build-up of slime growths in the river and, an attempt to accurately determine the velocity of the river, so that tests could be run on the same slug of water in the river, as it moved downstream.

2. Necessity for Oxygen

Dissolved oxygen is the most important factor in determining the health of a natural stream, not only from the point of view of the survival of fish life but also from the aesthetic and recreational aspects of the stream (Hoak & Bramer 1961). Furthermore, oxygen is the most important element in biological systems, for without oxygen, no microbial growth or utilization of organic material is possible. While oxygen which is chemically combined in a stream is more important to microorganisms than is dissolved oxygen (McKinney 1956), the deficit

of the latter has been extensively utilized as a measure of the pollution which has occurred in a stream or river.

3. Dissolved Oxygen Deficit

The rate of deoxygenation in a polluted water and its corresponding reoxygenation, or reaeration, from the atmosphere has been presented in the classical work of Streeter and Phelps (1925). The differential equation used to describe the combined action of deoxygenation and reaeration is as follows:

$$\frac{dD}{dt} = K_1 L - K_2 D \qquad (1)$$

This equation states that the net rate of change of the oxygen deficit, D (p.p.m.), is independently proportional to the B. O. D., L(p.p.m.), and the dissolved oxygen deficit. The proportionality factor, K_1, is dependent upon temperature. K_2 is also a temperature function but, more importantly, is dependent upon the stream turbulence.

Since the time of the presentation of equation (1), many attempts have been made to establish values of K_1 and K_2 for particular rivers. The studies conducted have shown that many additional factors play an important part in the deoxygenation and reaeration of natural streams. These agents, enumerated by Dobbins (1964) are as follows:

(i) The removal of B. O. D. by sedimentation or adsorption.

(ii) The addition of B. O. D. along the reach by scour of bottom deposits or by the diffusion of partly decomposed organic products from the benthal layer into the water above.

(iii) The addition of B. O. D. along the stretch by the local runoff.

(iv) The removal of oxygen from the water by the purging action of gases from the benthal layer.

(v) The removal of oxygen from the water by diffusion into the benthal layer to satisfy the oxygen demand in the aerobic zone of this layer.

(vi) The addition of oxygen by the photosynthetic action of plankton and fixed plants.

(vii) The removal of oxygen by the respiration of plankton and fixed plants.

(viii) The continuous redistribution of both the B. O. D. and oxygen by the effect of longitudinal dispersion.

These factors have been combined by Dobbins, into a theoretical dissolved oxygen deficit equation based on the following idealized assumptions:

(i) The stream flow is steady and uniform.

(ii) The process for the stretch as a whole is a steady state process, the conditions at every cross section being unchanged with time.

(iii) The removal of B. O. D. by both the bacterial oxidation and the sedimentation or adsorption or both are first order reactions, the rates of removal at any section being proportional to the amount present.

(iv) The removal of oxygen by the benthal demand and by plant respiration, the addition of oxygen by photosynthesis, and the addition of B. O. D. from the benthal layer or the local runoff are all uniform along the stretch.

(v) The B. O. D. and oxygen are uniformly distributed over each

cross section, thus permitting the equations to be written in the usual one-dimensional form. The differential equation proposed by Dobbins is:

$$D_L \frac{d^2C}{dx^2} + K_2(C_s - C) - V \frac{dC}{dx} - K_1 L - D_B = 0 \qquad (2)$$

where, D_L is the coefficient of longitudinal dispersion (sq. ft. per day); x represents the distance positively downstream along the stretch (ft.); C_s is the oxygen saturation value (p. p. m.); C denotes the oxygen concentration (p. p. m.); V represents the average stream velocity (ft./day); D_B stands for the net rate of removal of oxygen by the benthal demand and the effect of plants (p. p. m./day); and K_1, K_2 and L are as previously defined.

The introduction of proper boundary conditions allows this equation to be integrated with the following result:

$$D = \frac{K_1\left(L_A - \frac{La}{K_1 + K_3}\right)(e^{mx} - e^{rx})}{K_2 - (K_1 + K_3)} + D_o e^{rx} + \left(\frac{D_B}{K_2} + \frac{K_1 L_a}{K_2(K_1 + K_3)}\right)(1 - e^{rx}) \qquad (3)$$

where, $D = C_s - C$, the dissolved oxygen deficit (p. p. m.); L_A denotes the initial B. O. D. (p. p. m.); L_a represents the rate of addition of B. O. D. along the stretch (p. p. m. per day); K_3 is the rate constant for B. O. D. removal by sedimentation or adsorption; D_o stands for the initial dissolved oxygen saturation deficit (p. p. m.); and

$$r = \frac{V - \sqrt{V^2 - 4K_2 D_L}}{2D_L} \qquad (4)$$

$$m = \frac{V - \sqrt{V^2 + 4(K_1 + K_3)D_L}}{2D_L} \qquad (5)$$

By neglecting the coefficient of longitudinal dispersion and by making simplifying assumptions for the values of m and r, equation (3) is brought to the following form:

$$D = \frac{K_1\left(L_A - \frac{La}{K_1+K_3}\right)\left(e^{-(K_1+K_3)t} - e^{-K_2t}\right)}{K_2 - (K_1 + K_3)} + D_o e^{-K_2t} + \left(\frac{D_B}{K_2} + \frac{K_1 L_a}{K_2(K_1+K_3)}\right)(1-e^{-K_2t}) \qquad (6)$$

Dobbins' equation (6) is in a form similar to that proposed by Camp (1965). Lynch (1965) has pointed out that the use of the simplifying assumptions mentioned above would lead to an error not exceeding 4%, and that he agrees "that the effect of the longitudinal dispersion is negligible." Equation (6) has not been presented as being the ultimate in mathematical formulation for the dissolved oxygen deficit, but rather, as an indication of the many parameters which play a significant role in the D. O. depletion. Thackston and Krenkel (1965) have indicated this by noting that, as more data become available and the individual processes become better understood, the above equation may be expanded or improved.

4. Dissolved Oxygen Under Ice Cover

The conditions which exist on the North Saskatchewan river during winter ice cover have the effect of eliminating some of the deoxygenation and reaeration factors previously mentioned. Ice cover effectively prevents atmospheric reaeration and greatly reduces the possibility of both respiration and photosynthetic action by phytoplankton and fixed plants. The remaining factors in the D. O. deficit formulation are then:

(i) The removal of B. O. D. by sedimentation or adsorption.

(ii) The addition of B. O. D., by the scour of bottom deposits, from local runoff, and by diffusion of partly decomposed organic products from the benthal layer into the water above.

(iii) The removal of oxygen by diffusion into the benthal layer to satisfy the oxygen demand of the aerobic zone of this layer and by the purging action of gases from the benthal layer.

(iv) The continuous redistribution of both the B. O. D. and oxygen by the effect of longitudinal dispersion.

In the attempted formulation of the dissolved oxygen deficit in the North Saskatchewan river under ice cover, careful consideration must be given to the above elements as well as to the rates of dissolved oxygen uptake by the B. O. D. in the river.

5. Biochemical Oxygen Demand

Biochemical oxygen demand is usually defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions (Sawyer, 1960). B. O. D. is found to develop, for a polluted water, or waste water, in two stages. The first of these, referred to as the carbonaceous stage, is most often formulated by the monomolecular equation:

$$-\frac{dL}{dt} = K L \qquad (7)$$

which, when integrated, leaves:

$$y = L(1 - 10^{-kt}) \qquad (8)$$

in which y is the B. O. D. (p. p. m.) at any time t; L stands for the

ultimate value of B. O. D. (p. p. m.) and K is a rate constant. In the carbonaceous stage, organic carbon is oxidized by biological agencies. FIGURE 11 shows a typical carbonaceous stage of B. O. D.

The second stage of the B. O. D. curve is referred to as the nitrogenous portion of the curve. In this region, the following reactions take place (Sawyer 1960).

$$2NH_3 + 3O_2 \xrightarrow[\text{bacteria}]{\text{nitrite forming}} 2NO_2^- + 2H^+ + 2H_2O \qquad (9)$$

$$2H^+ + O_2 + 2NO_2^- \xrightarrow[\text{bacteria}]{\text{nitrate forming}} 2NO_3^- + 2H^+ \qquad (10)$$

It has been commonly accepted that the nitrogenous stage of B. O. D. lags behind the carbonaceous stage by several days (FIGURE 11). Courchaine (1963) has found, however, in his studies of the Grand River in Michigan, that the two stages occur almost simultaneously (FIGURE 12). This apparent conflict confirms McKinney's (1962) statement, that changing conditions may change the rate of metabolism of the microorganisms present thus causing a wide variation in results. It is therefore essential that an individual situation be treated on its own merits.

The B. O. D. profile for a stream has been formulated by Dobbins (1964) in a manner similar to the formulation for D. O. Based on the assumptions previously mentioned the equation is given by:

$$L = L_A e^{mx} + \frac{L_a}{K_1 + K_3}(1 - e^{mx}) \qquad (11)$$

in which the terms are as previously defined.

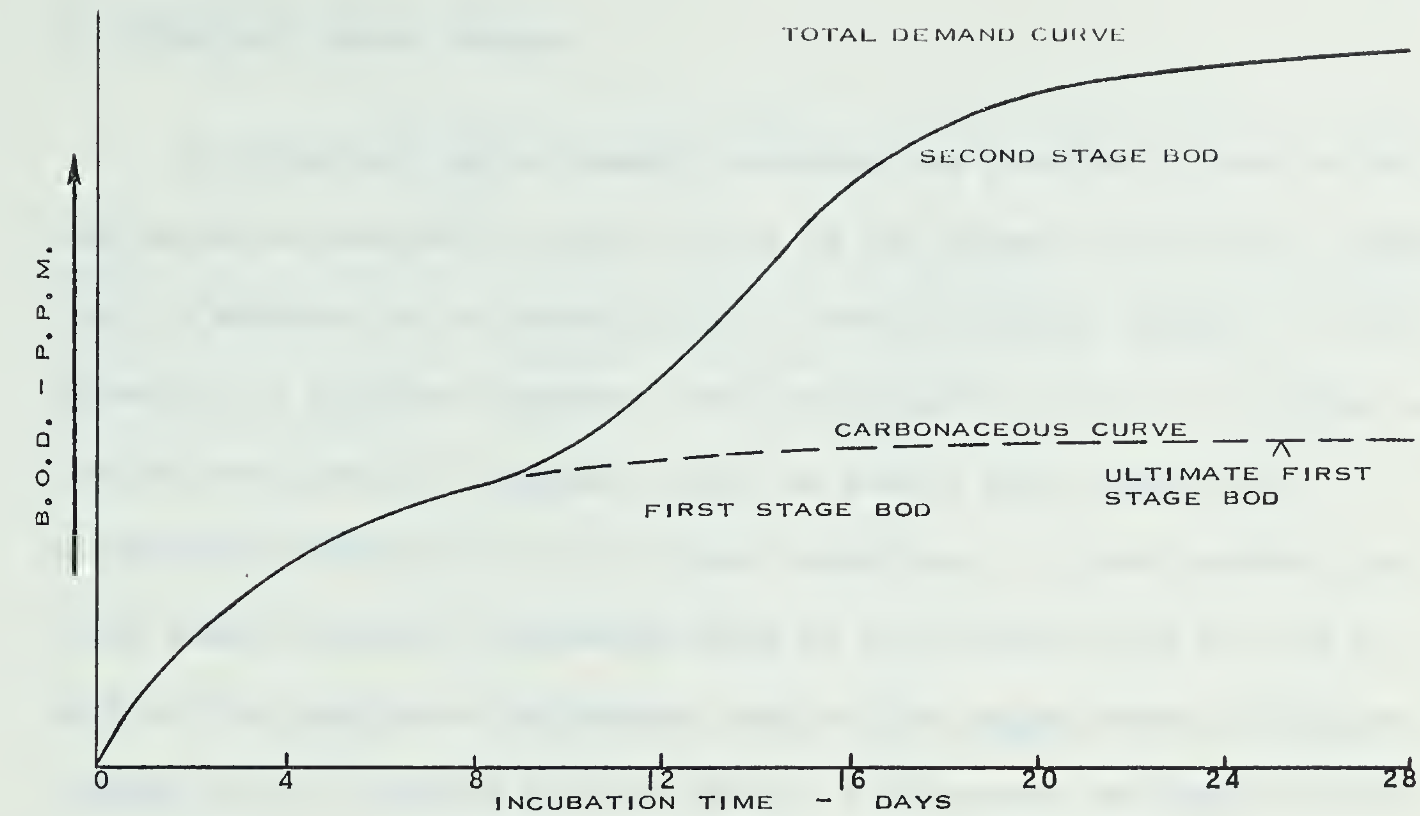

FIGURE 11 GENERALIZED TWO STAGE OXIDATION OF ORGANIC MATTER

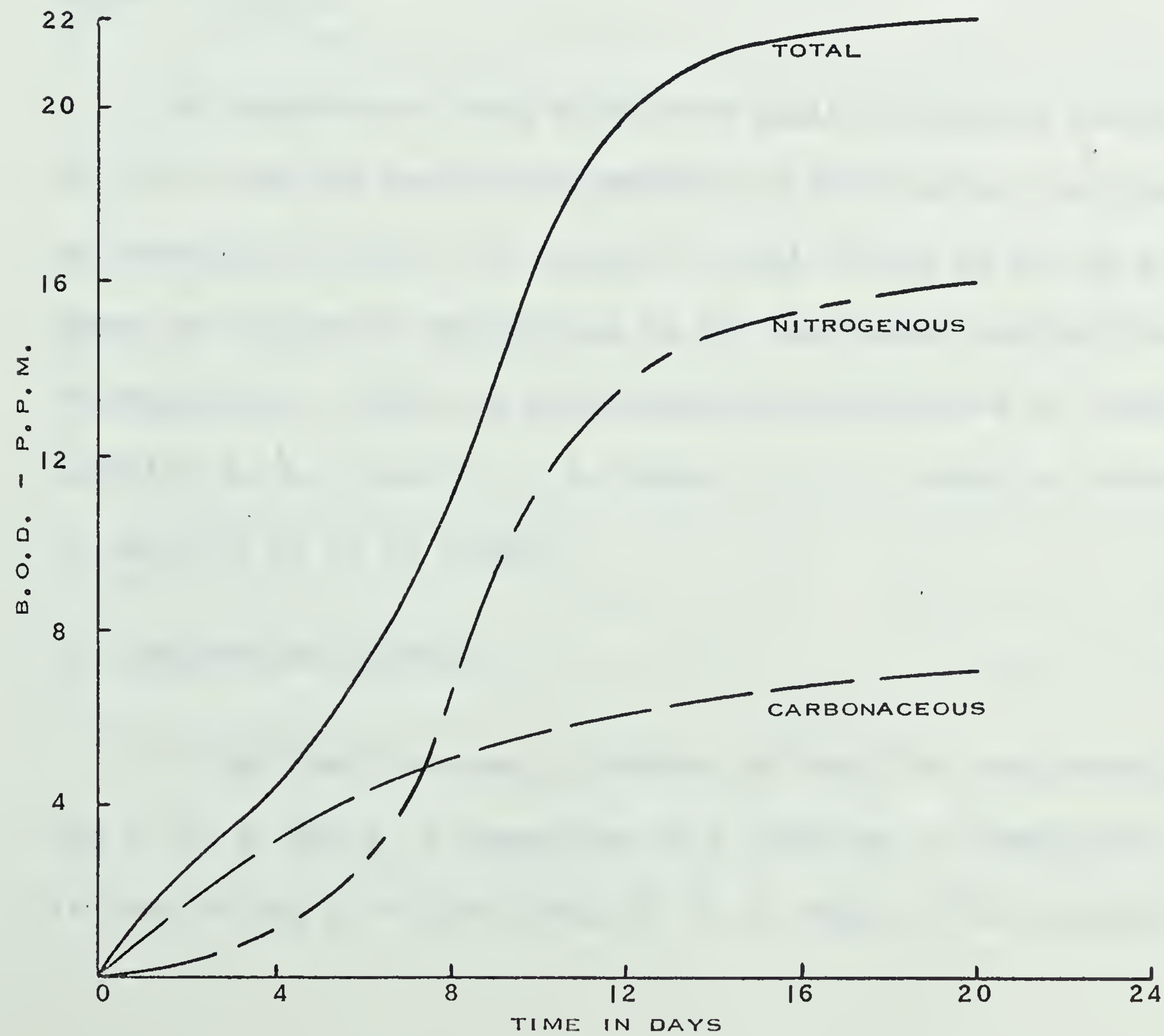

FIGURE 12 BOD CURVES FOR THE GRAND RIVER LANSING, MICHIGAN

6. Chemical Oxygen Demand

The chemical oxygen demand determination provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. In the absence of a catalyst, however, the determination of C. O. D. fails to include some organic compounds, such as acetic acid, which are biologically available to the stream organisms. It does however, include some biological compounds, such as cellulose, which are not a part of the immediate biochemical load on the oxygen assets of the receiving water (Standard Methods 1965). Furthermore, as Sawyer (1960) has discussed, the C. O. D. test does not indicate the rate at which biologically active material would be stabilized under conditions that exist in nature.

In cases where toxic substances limit biological activity, the C. O. D. test may be the only method for determining the organic load. An advantage of the C. O. D. test is that it can be run in a matter of three or four hours rather than in the five days required for B. O. D. determinations. With the accumulation of experience in running comparative B. O. D. and C. O. D. tests, C. O. D. data can often be used in terms of B. O. D. values.

7. Temperature Effects

It has been previously pointed out that the rate constant K_1 in the B. O. D. and D. O. equations is a function of temperature. The same is true of the L or first stage B. O. D. value. The accepted temperature

relationship for K_1 is:

$$\frac{K_{1(T_1)}}{K_{1(T_2)}} = \theta^{(T_1-T_2)} \qquad (12)$$

where $K_{1(T_1)}$ and $K_{1(T_2)}$ are K_1 values at temperatures of $T_1{}^{o}C$ and $T_2{}^{o}C$ respectively. θ is a thermal coefficient with a value of 1.0241 (A. S. C. E. 1961).

For the first stage B. O. D.,

$$L_T = L_{20}\left[1 + 0.02(T-20)\right] \qquad (13)$$

where L_T and L_{20} are the ultimate first stage B. O. D.'s at T^oC and 20^oC.

In the standard B. O. D. test, samples are incubated immediately after collection, for a period of five days at a constant temperature of 20^oC. It is generally found that the B. O. D. value at this time is approximately 68% of the ultimate first stage B. O. D. Studies by Briggs (1966) confirm that K_1 and L values are reduced by decreased temperatures in laboratory studies. Briggs also mentions that, in his laboratory tests at 0^oC to 5^oC on domestic sewage, essentially no nitrification took place for periods of up to seventy days.

A further effect of temperature which is critical in the present study is the solubility of oxygen in water. Studies by the Sanitary Engineering Research Committee of the A. S. C. E. (1960) report dissolved oxygen saturation values as listed in TABLE VI.

TABLE VI

DISSOLVED OXYGEN SATURATION VALUES IN DISTILLED WATER
(Corrected to atmospheric pressure of 760 mm. Hg)[a]

Temp °C	D. O. mg./l.	Temp °C	D. O. mg/l
0	14.65	15	10.03
1	14.25	16	9.82
2	13.86	17	9.61
3	13.49	18	9.40
4	13.13	19	9.21
5	12.79	20	9.02
6	12.46	21	8.84
7	12.14	22	8.67
8	11.84	23	8.50
9	11.55	24	8.33
10	11.27	25	8.18
11	11.00	26	8.02
12	10.75	27	7.87
13	10.50	28	7.72
14	10.26	29	7.58
		30	7.44

(a) Values vary in approximately direct proportion to the atmospheric pressure.

The above values are often used, in ordinary river and stream studies, with no correction being made for physical or chemical constituents in the water, which may change the saturation values. This is a reasonable approximation for, as shown by Fair, Geyer and Morris (1954), the decrease in saturation values per 100 mg./l chloride, varies from 0.0075 mg./l. at 30°C to 0.0165 mg./l. at 0°C.

8. Bottom Sediments

Sludge deposits in a watercourse polluted with organic wastes may

exert some oxygen demand upon the overlying water. Experimental studies have been conducted by Fair et al (1941) on the oxygen demand of such deposits for periods of up to 450 days at temperatures of 20°C and 25°C. From these studies Camp (1963) states that a depth of one meter of fresh sludge might be expected to exert an oxygen demand of 20 to 25 p. p. m. per day on a two meter depth of still water. A research report by the Sanitary Engineering Research Committee of the A. S. C. E. (1958) showed that bottom deposits may exert an oxygen demand, in some cases, as high as that exerted by the particular sewage flow itself.

The amount of sludge deposition on stream beds is related to the velocity. Mean velocities of one to two feet per second (f. p. s.) in the North Saskatchewan river during the winter, allow bottom sludges to build up within the reach twenty or thirty miles downstream from Edmonton. During the summer, mean velocities of from four to six f. p. s., tend to scour the river bed and remove these deposits. Thus, the river does not favor excessive formation of sludge blankets.

9. Biological Pollution Indicators

Increased interest has been shown, in recent years, in the use of the biological community in a river as a pollution indicator. Olson (1956) has remarked that the biological community will show the effects of long term pollution whereas physical and chemical data show the pollutional effect only at the time of sampling. Keup (1966) and King and Ball (1964) have suggested the use of certain specific macroorganisms such as aquatic insects, tubificid worms, stoneflies, mayflies and caddisflies, among others, as indicators of stream quality. While Paterson (1966) states

that Spirogyra spp. could be termed an indicator genus in the North Saskatchewan river, he expresses some misgivings about the whole concept of indicator organisms. While the use of a single species of organism may be used as an index, using the whole biological community will provide a broader basis for judgement of the stream characteristics.

The biological community-pollution indicator concept undoubtedly has a place in stream and river studies; however, like other parameters previously mentioned, a continuous program of sampling must be implemented in the river under study in order to determine the efficacy of the particular indicator.

CHAPTER IV

FIELD AND LABORATORY STUDY AND PROCEDURES

1. Introduction

The present study was undertaken in an attempt to formulate the bio-oxidation relationships occurring in the North Saskatchewan river under ice cover. A slug of water in the river would be followed, as it moved downstream, and values for the B. O. D., dissolved oxygen and C. O. D. obtained, from samples taken at suitable sampling points (FIGURE 13). To this end, the essential first step was a determination of the mean river velocities.

B. O. D. and C. O. D. values of the wastes entering the river, at the time of the passage of the slug of water, would be calculated.

Baskets filled with limestone rocks were also to be placed in the river at various locations in order to attempt an assessment of the possible build up of bottom slimes during the winter.

2. Velocity Determinations

An accurate measurement of the mean river velocity* required that some type of tracer be injected into the river in a quantity sufficient to permit the tracer concentration to be measured at some downstream point. Tracers which have been used extensively in river discharge measurements are fluorescent dyes, radioactive isotopes and soluble chemical salts.

* Not to be confused with mean velocity over the cross-sectional area of flow.

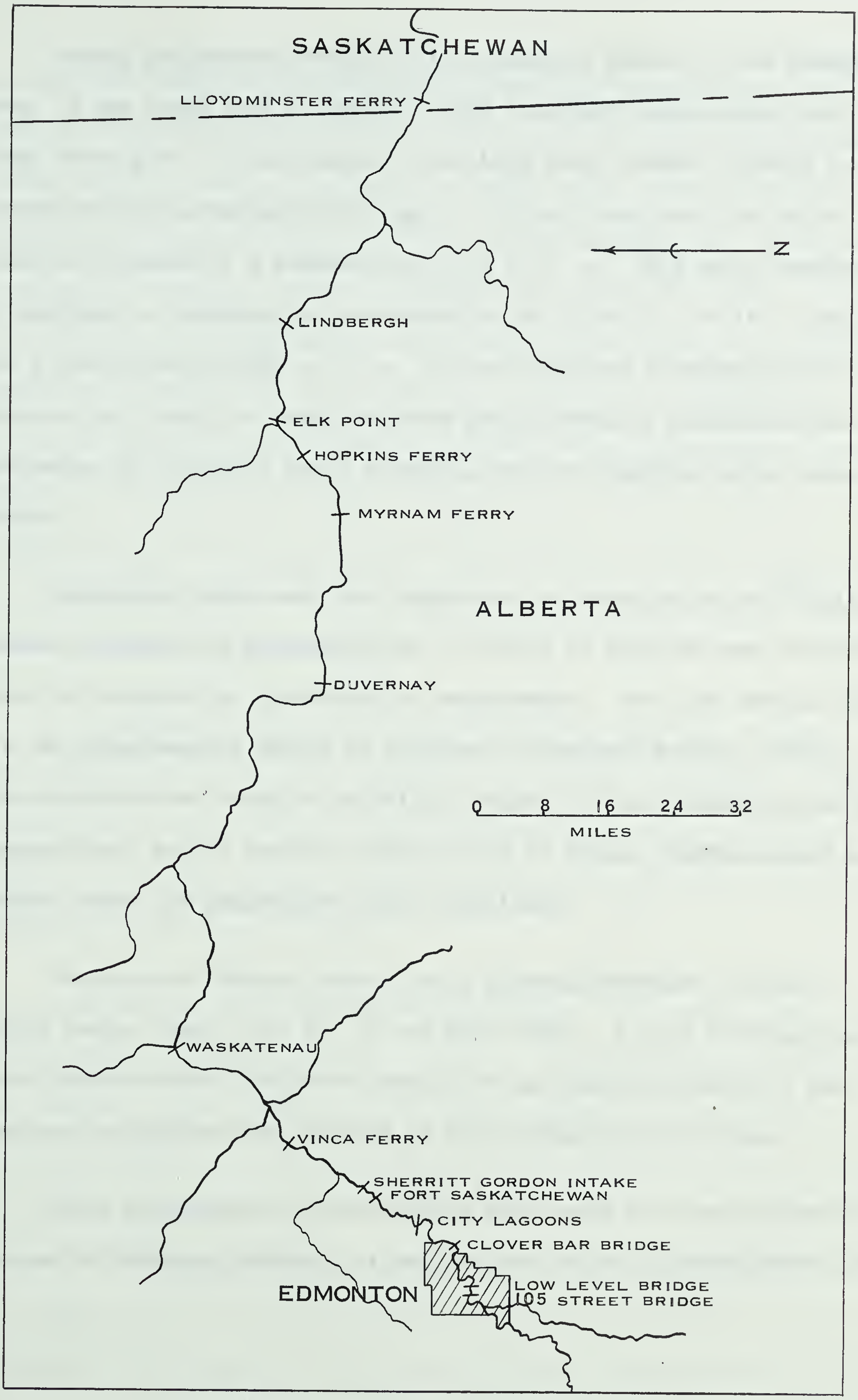

FIGURE 13 SAMPLING POINTS – N. SASKATCHEWAN RIVER

During preliminary contact with industrial plants in the Edmonton area, it was found that a chemical plant near Fort Saskatchewan had a large brine pond. Brine samples, from this pond, showed chloride ion concentrations exceeding 50,000 mg./l. It was found that the brine could be released at a maximum rate of 2 c. f. s. This would provide an increase in chloride ion concentration of 33 mg./l., in the river, for a river flow of 3000 c. f. s. It was felt that discharging the brine at this rate for twenty minutes would provide a measurable concentration at the Vinca Ferry crossing, the next sampling point downstream.

Laboratory tests were then conducted, on river water at $0^{\circ}C$ with various chloride ion concentrations, in order to find the most suitable means of chloride ion concentration measurement. The first method tried was the Argentometric Method as outlined in Standard Methods (1965). This procedure was found to be fairly accurate at low concentrations and temperatures, but it was felt that the use of liquid reagents would be awkward under low temperature field conditions.

The Mercuric Nitrate method using diphenylcarbazone indicator buffer powder (Hach, Cat. No. 8) was then tried. A poor titration end point combined with unreliable results at low concentrations and temperatures prohibited the adoption of this method for field use.

After appraising the difficulties which were to be encountered in the use of foregoing methods, it was decided to try a potentiometric means

of measuring sodium ion concentrations using an expanded scale pH meter and a sodium ion electrode. Brine from the pond previously mentioned was to be used as a source of sodium ions. It was realized that, for the same flow from the brine pond, concentrations of sodium ion would be lower than those calculated for the chloride ion. It was felt, however, that measurable concentrations would still be obtained. Background chloride ion concentrations, in the river, ranging from one to ten mg./l. in the winter of 1965-66, led to the assumption that sodium ion concentrations might be in the area of 0.4 to 4 mg./l. This background in the river, plus the added sodium ion from the brine pond was expected to provide a concentration high enough to be measurable with the sodium ion electrode.

The expanded scale glass electrode pH meter used was set for a full scale range of from one hundred to two hundred millivolts. From calibration curves supplied by the electrode manufacturer, this was expected to provide sodium ion concentration measurements of approximately 0.5 mg./l. to 37 mg./l. at 25°C.

Laboratory tests conducted on river water with various sodium ion concentrations confirmed the above values. During the laboratory testing, however, three problems arose which precluded the possibility of using this method. It was found that very slight motion of the solution around the electrodes caused the millivolt readings to drop rapidly to a point below the lowest scale marking. Secondly, the sensitivity of the meter was markedly decreased by the 0°C water temperature, and, finally, it was found that cold air temperatures seriously affected the

operation of the pH meter itself. These difficulties, while not insurmountable, presented a time problem. Ice had started to form on the river and a start on velocity measurements in the near future was essential. It was therefore decided that the Argentometric Method of chloride ion concentration would be utilized.

Before releasing the brine, it was necessary to obtain some idea of the mean velocity which might be expected in the river. For this purpose, three dozen large oranges were purchased and dumped into the open water near the power plant. Oranges were used because they were clearly visible through the water vapor rising from the river at cold temperatures and, as they floated low in the water they were not strongly affected by wind and small waves.

The travel time from the power plant to the Main Sewage Treatment Plant was measured and a mean velocity calculated. From this information, the velocity under ice cover was approximated from Fort Saskatchewan to Vinca Ferry. Individual travel times were also calculated for the river distances between all of the municipal and industrial waste water effluents in the area.

During the period in which the preceding tests were being conducted, ice had started to form. First ice appeared on November 8, 1966 and, by December 2, the ice at Vinca Ferry was thick enough to support the weight of an automobile.

Permission to discharge the brine into the river had been previously sought and obtained from the Sanitary Engineering Division of the Alberta

Department of Public Health, and plans were made to release the brine at 7:00 A. M. on December 17. On the basis of the velocity calculations, the run was started at 8:15 A. M., December 16 from the 105th Street bridge. As the slug of water passed each waste water effluent, a sample of the waste water was obtained and an estimate of waste water discharge made. (Measured values were later obtained from the records of each plant.) River water samples were taken at the various sampling points along the river as the slug of water passed. On the morning of December 17, at the calculated time of arrival of the slug of water, the brine was released to the river. During release, a sample was taken so that the chloride ion concentration could be determined. Instead of the expected value of over 50,000 mg./l., the analysis showed a concentration of about 20,000 mg./l. On this basis, the chloride ion concentration in the river at the point of discharge was approximately 10 mg./l. It was expected that this would probably produce a maximum value of only one or two mg./l. at Vinca Ferry and that this would not be detectable.

In spite of this, the titration apparatus was set up at Vinca Ferry on the afternoon of December 17. Samples were collected and titrated every ten minutes for a period of eight hours. This period allowed for four hours in advance and four hours after the expected time of arrival of the wave of brine. Small fluctuations in chloride ion concentration were noted, but no evidence of a passing wave of higher concentrations was found. Thus, no accurate determination of mean velocity could be made from this run. It was later determined that the brine in the pond had become diluted by runoff water from melting snow, and by discharge

of cooling water from the plant into the pond. This occurrence made it necessary to then turn to other tracer methods.

The use of radioactive isotope tracer techniques was considered at this time. Schuster (1965) had used this method, with success, in the measurement of canal discharges. It was found, however, that permission to use radioactive isotopes, for the purposes of this study, would require a considerable length of time. It was then decided, that, in order to obtain velocity measurements without further delay, a fluorescent dye called Rhodamine B would be used as a tracer.

Rhodamine B had been found to be a relatively cheap, non-toxic, readily detectable dye. With the use of proper equipment, concentrations as low as 0.05 parts per billion (p. p. b.) could be detected (Buchanan, 1964). Rhodamine B was also well suited for this study because of its increased fluorescence at low temperatures and the stability of its fluorescence at pH values of from 5 to 10. Fuerstein and Selleck (1963), had pointed out however, that Rhodamine B was more susceptible to adsorption by suspended solids than were other commonly used dyes such as fluorescein and Pontacyl Brilliant Pink B. The ready availability of Rhodamine B however, justified its use in this study.

The measurement of the fluorescence of Rhodamine B in solution was accomplished by using a Coleman model 12C electronic photofluorometer. In this instrument, light from an ultra-violet lamp passes through a primary colored glass filter into the sample. This filtered light, having the proper wave length for the fluorescent dye used, excites the dye molecules to fluorescence. This fluorescence has a different wave

length of light. The fluorescent light passes through a secondary colored glass filter, at right angles to the primary filter, and strikes a photomultiplier tube. The photomultiplier tube then activates a meter, which provides a reading in direct proportion to the concentration of dye in the sample. Rhodamine B has a maximum adsorption spectrum at 550 millimicrons (m. u.) and a maximum fluorescent spectrum at 580 m. u. Thus, by careful filter selection, nearly monochromatic exciting light may be passed into the sample, and spurious scattered light to the photomultiplier tube may be considerably reduced.

Before using the photofluorometer in the field, river water samples were obtained and a series of dye concentrations set up for the purpose of calibrating the instrument. Before calibration however, it was necessary to make a proper selection of filters. A series of ten broad range filters was available for use with this instrument. All possible filter combinations were tried with a known dye concentration, and the filters giving optimum results were chosen. The photofluorometer was then calibrated and a calibration curve made up (FIGURE 14). It was found that, with stable line voltage and the filters available, the lowest reading obtainable with reasonable accuracy was in the order of 0.5 p. p. b. A laboratory check of the use of the fluorometer with a portable generator indicated that, because of voltage fluctuations, the lowest reliable reading obtainable was 1.0 p. p. b.

The photofluorometer was used in the field, with a Homelite Model 35A115, 1500 watt portable A. C. generator and a Coleman, Sta - Bal Model 12-357 voltage stabilizer (FIGURE 15).

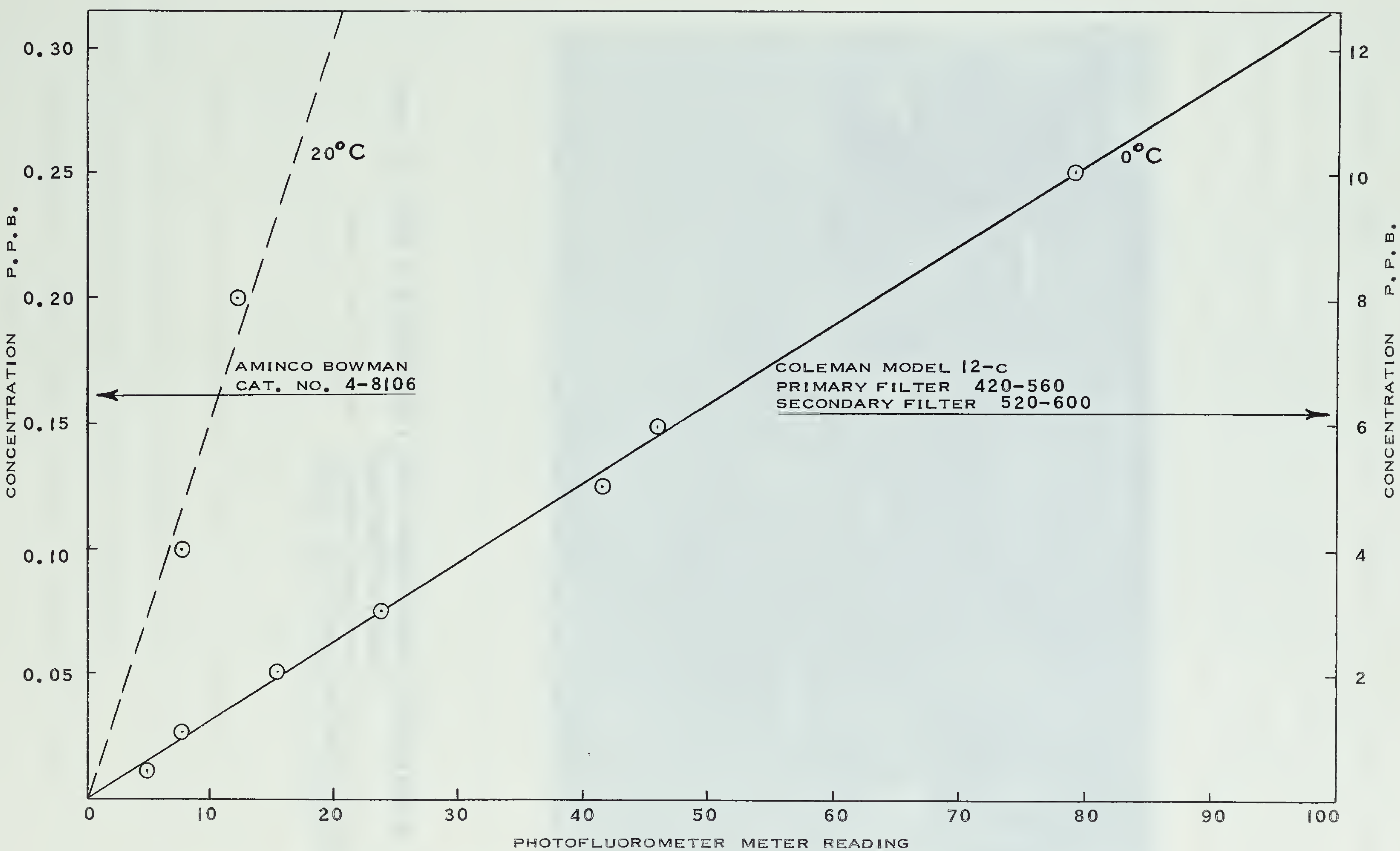

FIGURE 14 PHOTOFLUOROMETER CALIBRATION CURVES FOR RHODAMINE B DYE

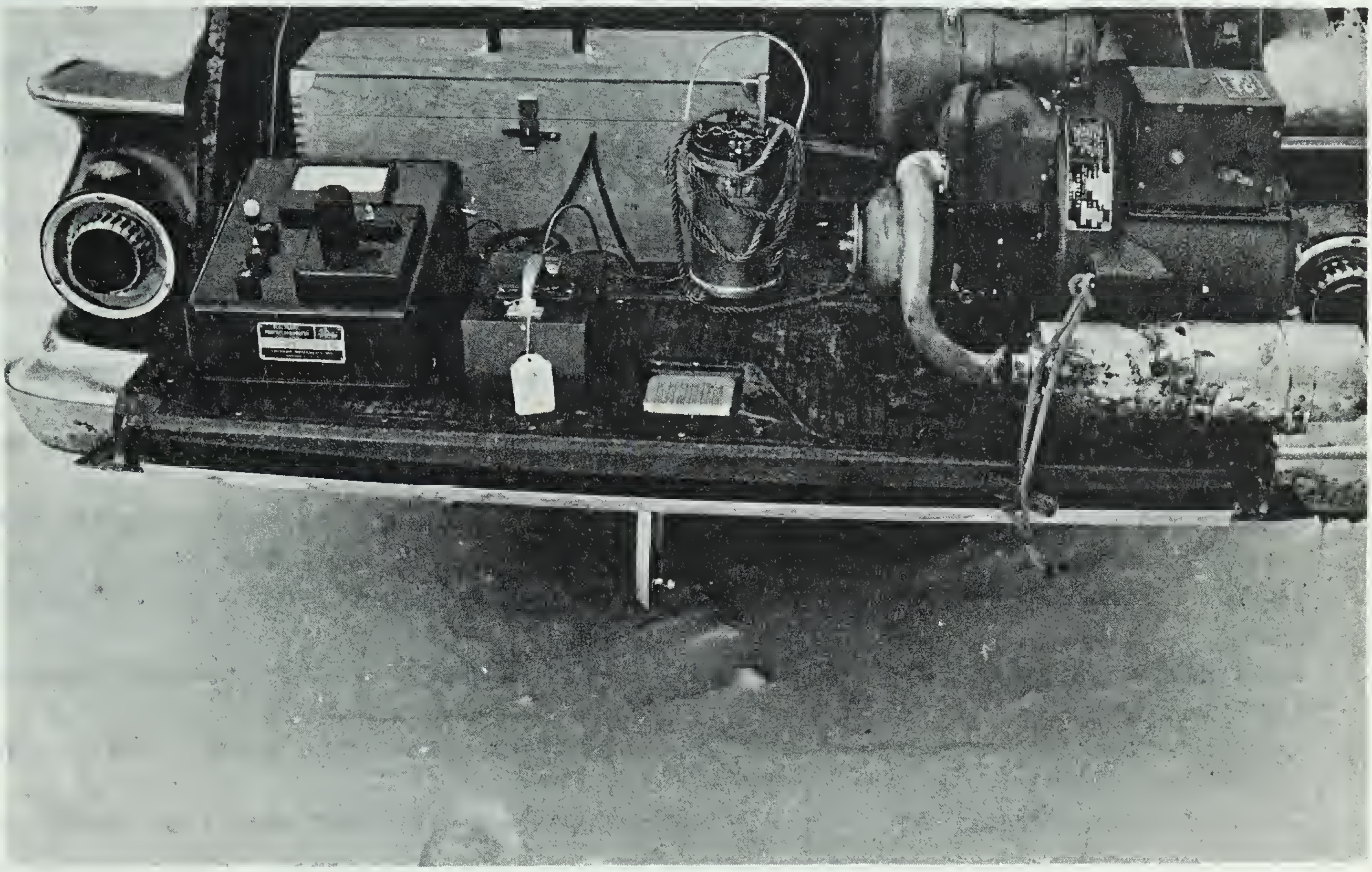

FIGURE 15 FIELD EQUIPMENT FOR MEASURING RHODAMINE B DYE CONCENTRATIONS

FROM LEFT TO RIGHT – PHOTOFLUOROMETER, VOLTAGE STABILIZER, SAMPLING CAN AND PORTABLE GENERATOR

Two test runs were made with the Rhodamine B. In the first run, five lbs. of dye, in powder form, was dropped into open water downstream from Fort Saskatchewan over a fifteen minute period. At each sampling point, river water samples were taken at ten to fifteen minute intervals and fluorometer readings obtained immediately. In this first run, samples were collected at Vinca Ferry and the travel time of the dye wave determined. The total travel distance was nearly 13½ miles. It was noted at this time that the maximum dye concentration had been reduced from approximately 28 p. p. b. to 4 p. p. b. during the time of travel. With this in mind, the quantity of dye purchased for the second run was increased to 10 lbs. and the duration of the injection time reduced to ten minutes. In this second run, the dye was introduced through a hole in the ice directly above the main river channel, at the Myrnam Ferry crossing (FIGURE 13). Water was pumped from a second hole in the ice, just upstream, into the hole where the dye was introduced, in order to force the dye down into the river. Dye concentration measurements were taken, in the field, at Hopkins Ferry and at Elk Point. It was found that peak dye concentrations were so low at Lloydminster Ferry, the portable fluorometer did not show the passing wave. Therefore, samples were collected, at this point, and brought back to Edmonton where they were passed through a larger, more sensitive photofluorometer. This fluorometer, an Aminco Bowman Cat. No. 4-8106 model was also calibrated at this time (FIGURE 14). In this manner, a portion of the passing wave was defined and an approximate value of the mean river velocity from Elk Point to Lloydminster determined.

Two further problems became evident during the course of these

velocity runs. It was found that, as long as the samples were put into the cuvette holder in the fluorometer and readings taken immediately, the results would remain consistent. If however, the samples were allowed to become warm, the readings would decrease markedly. Secondly, because of the variation in background fluorescence of the river water itself, it was noted that the sensitivity of this particular equipment was reduced and that readings below 1.5 p. p. b. were not to be relied upon.

3. Slime Build-up Measurement

During the planning stages of this study, it was felt that some assessment should be made, of the possible build-up of slimes and sludges, downstream from the points of pollutional loadings to the river. It was decided to utilize a type of limestone filled sampler similar to that suggested by Anderson and Mason (1966), and to place these samplers on the river bottom at various locations.

In order to keep the limestone rock surface area in each sampler in the same order of magnitude, the samplers were made the same size, the total weight of rock in each was made the same, and the same number of stones was put in each basket. The baskets were made from ½ inch hardware cloth and were cylindrical in shape (FIGURE 16).

Baskets were placed at the sampling sites at the 105th Street bridge, the City lagoons, Vinca Ferry and Lloydminster Ferry. Holes were drilled through the ice with an 8 inch ice auger, and the baskets lowered to the river bottom with a rope. The free end of the rope was tied to a piece of 2" x 2" lumber which had previously been sharpened and driven

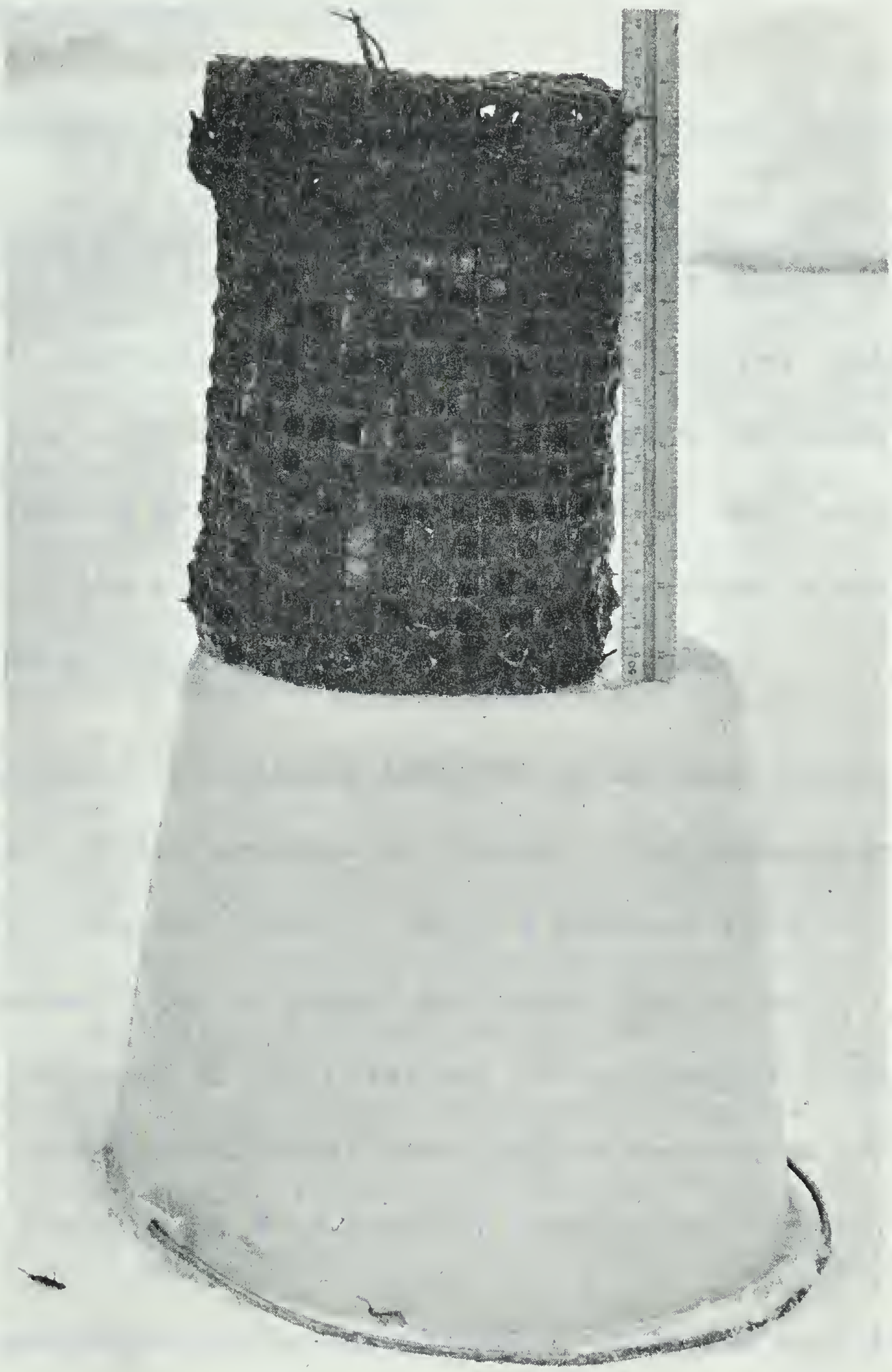

FIGURE 16 LIMESTONE FILLED SAMPLING BASKET
NOTE SLIME BUILD-UP ON BASKET WIRES AND
STONEFLY NYMPH ON SNOW AT LOWER LEFT

into the river bottom. Three to four feet of the 2 x 2 was left showing above the ice to serve as a marker.

The baskets were removed from the river at certain intervals by drilling a hole through the ice and fishing for the rope with a long hooked wire. The rope used was a polypropylene rope which had the disadvantage that it floated. This made it difficult to get enough rope down under the ice to provide enough slack to remove the basket easily. This created a further problem on one occasion as it was found that rapid movements of the rope to pull up the basket caused a considerable portion of the slime build up to slough off the basket.

After removal of the baskets from the river, each basket was visually examined for the presence of insects. The stones were then carefully removed from the basket. Using a pressure sprayer, the slimes and muds were washed from the stones and basket into a pail. The clean basket was then replaced in the river and the wet samples brought into the laboratory. Small portions of some samples were taken for microscopic examination and the balance evaporated to dryness and weighed.

In the areas where bottom deposits were thick and soft the baskets had a tendency to sink into the mud and a certain amount of this bottom material was therefore brought up with the baskets. The use of a flat, rectangular basket instead of the cylindrical type used in this study, would have a lower unit pressure and thus reduce the propensity to sink. This flat type of basket would more closely simulate river bottom conditions and it would have most of its volume close to the river bottom

where velocities are lower and there is a reduced possibility of material being scoured from the basket.

4. Dissolved Oxygen Survey

River samples for D. O. measurements were taken with a sampling can (FIGURE 15), similar to that suggested by Standard Methods (1965). The can was sized so that it would pass easily through an eight inch hole in the ice and would also provide three complete changes of water in the B. O. D. bottle inside. Extra weight was attached to the bottom of the can to ensure that the can would sink into the main river stream quickly and thus avoid picking up the relatively stagnant water held in the auger hole.

The Modified Azide method for the determination of dissolved oxygen was used throughout the study (Standard Methods, 1965). Porges (1964) had noted that field D. O. samples could be preserved for several days by adding all reagents and keeping the sample in the dark at ice temperature. In this study, it was necessary to keep samples in the field for periods of up to four days. As it was impractical to keep these samples at ice temperatures experiments were carried out in the field to determine the effect of keeping the acidized samples in the dark for extended periods at temperatures varying from 0°C to 20°C.

It was found that acidized samples, kept for one or two days under the above conditions, showed no change in dissolved oxygen readings. D. O. values, for samples kept longer than two days, were consistently lower than the true value. It was therefore necessary to carry out

immediate field titration on D. O. samples which could not be titrated in the laboratory within 36 hours.

5. B. O. D. Determinations

Values for B. O. D. were obtained by following the procedures outlined in Standard Methods (1965). The major problem, again, was the matter of sample storage. As it was impractical to set up the B. O. D. bottles and incubate them at 20°C in the field, it was decided to collect the samples in polyethylene bottles which had been cleaned with chromic acid, and to freeze them immediately. Experiments conducted by the Sanitary Engineering Division of the Alberta Department of Public Health indicated that freezing river samples for three to four days before running B. O. D. tests had no appreciable effect on the results. This was confirmed by field tests conducted in this study.

The frozen samples from each sampling point were brought into the laboratory, warmed to 20°C, agitated to remove excess dissolved oxygen and set up in four B. O. D. bottles. One bottle was used to determine the initial D. O. and the remaining three placed in the 20°C incubator for the required five day period, after which B. O. D. tests were run.

6. Measurement of C. O. D. Values

The procedure for dilute samples as outlined in Standard Methods (1965) was followed in C. O. D. determinations. As pointed out in Standard Methods, extreme care had to be taken with this method because small traces of organic matter in the glassware or atmosphere could lead to gross errors. The titration end point for dilute samples was found to

be less precise than that for strong samples, and a certain amount of judgment had to be exercised by the operator in end point determination.

7. River Discharge

The knowledge of the river discharge at any given time was of importance in this study, not only for the determination of river velocities and dye concentrations, but also for the calculation of expected river B. O. D. from the knowledge of individual plant loadings to the river. It was also found desirable to be able to ascertain that the river flow was remaining fairly constant during each run. As allowable B. O. D. and other loadings from industrial plants and sewage treatment plants are related directly to the flow in the river, individual plant operators must also know the daily value of river discharge.

The determination of river discharges for this study and for plant operators was complicated by the fact that there is only one accurate stage-discharge gauging station on the North Saskatchewan river in Edmonton. This station, has a twenty four hour recording gauge, is located at the low level bridge and is operated by the Water Resources Branch of the Federal Department of Energy, Mines and Resources. The office of this department is located in Calgary, Alberta, and receipt of river discharge data in Edmonton is often delayed for periods up to ten days.

A stage measuring station is operated at the City of Edmonton power plant and daily maximum discharges are available upon request from this source. However, as shown in APPENDIX A, the discharge results from this

source, particularly at low flows vary widely from those of the Federal Government. The effect of rising and falling stage and backwater due to ice is not taken into consideration in the determination of discharge from the power plant rating curve. The power plant gauge itself is located inside the raw water intake structure and is thus affected by clogging of the screens, back washing of the intake pipe lines, entrance energy losses and water level variations caused by rapid changes in pumping rate.

However, in order to estimate the river flow each day, a rating curve of mean daily stage at the Power Plant versus the mean daily discharge at the low level bridge was plotted (APPENDIX A). It was realized that this procedure did not conform with accepted practise for the transfer of rating curves from one point on a river to another. However, it did provide a reasonable measure of the river flow each day.

CHAPTER V

STUDY RESULTS AND OBSERVATIONS

1. Velocity Determinations

It had been hoped, initially, that velocity measurements could be made on each of the reaches, between sampling points, from Edmonton to Lloydminster Ferry. With the many problems which arose and with the limited time available, it was not possible to carry out this program.

Mean velocities were determined for the following reaches; the Dow Chemical effluent near Fort Saskatchewan to Vinca Ferry; Myrnam Ferry to Hopkins Ferry; and Hopkins Ferry to Elk Point. An approximate mean velocity was also determined for the reach from Elk Point to Lloydminster Ferry. A graphical summary of the run from Dow Chemical to Vinca Ferry is given in FIGURE 17 and the run from Myrnam Ferry to Lloydminster Ferry in FIGURE 18.

The values for mean velocities were substituted in the Manning equation:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} \qquad (14)$$

where V is the mean velocity (f. p. s.); n is a roughness factor; S denotes the average bed slope (ft./ft.) and R represents the hydraulic radius;

$$\text{or } V = KS^{\frac{1}{2}} \qquad (15)$$

where K is called the conveyance. The values of velocity and conveyance

thus determined are tabulated in TABLE VII.

TABLE VII

CALCULATED VELOCITIES AND CONVEYANCE FACTORS
APPROXIMATE DISCHARGE = 3000 C. F. S.

From	To	Centreline Distance ft.	Peak to Peak Time hrs.	Mean Water Slope ft/ft $\times 10^4$	Apparent Mean Velocity ft/sec	Conveyance K
Dow	Vinca	70600	12.72	3.31	1.54	84.6
Myrnam	Hopkins	51050	10.33	2.35	1.37	89.5
Hopkins	Elk Point	33250	7.59	1.81	1.22	90.7
Elk Point	Lloyd.Ferry	265900	About 53	2.93	1.39	81.3

As mentioned in Chapter IV, the dye injected at the Dow Chemical Effluent was introduced into open water near the shore. This would have the effect of reducing both the apparent mean velocity and the value of K.

On the Elk Point - Lloydminster Ferry reach, only the beginning of the dye wave was pin-pointed, and the dye concentrations measured were very low. Thus, the velocity and K values given are only approximate.

FIGURE 18 illustrates two points of interest which must be considered in velocity measurements of this type. The first is, the rapid decrease in maximum levels of concentration and the spread of the base of the curve as the wave moves downstream. Secondly, the lag time and difference in peak dye concentrations at Elk Point, between observations near the shore and in the centre of the river. A further point to which attention should be given is the possibility of inaccuracies in the values for the slope of

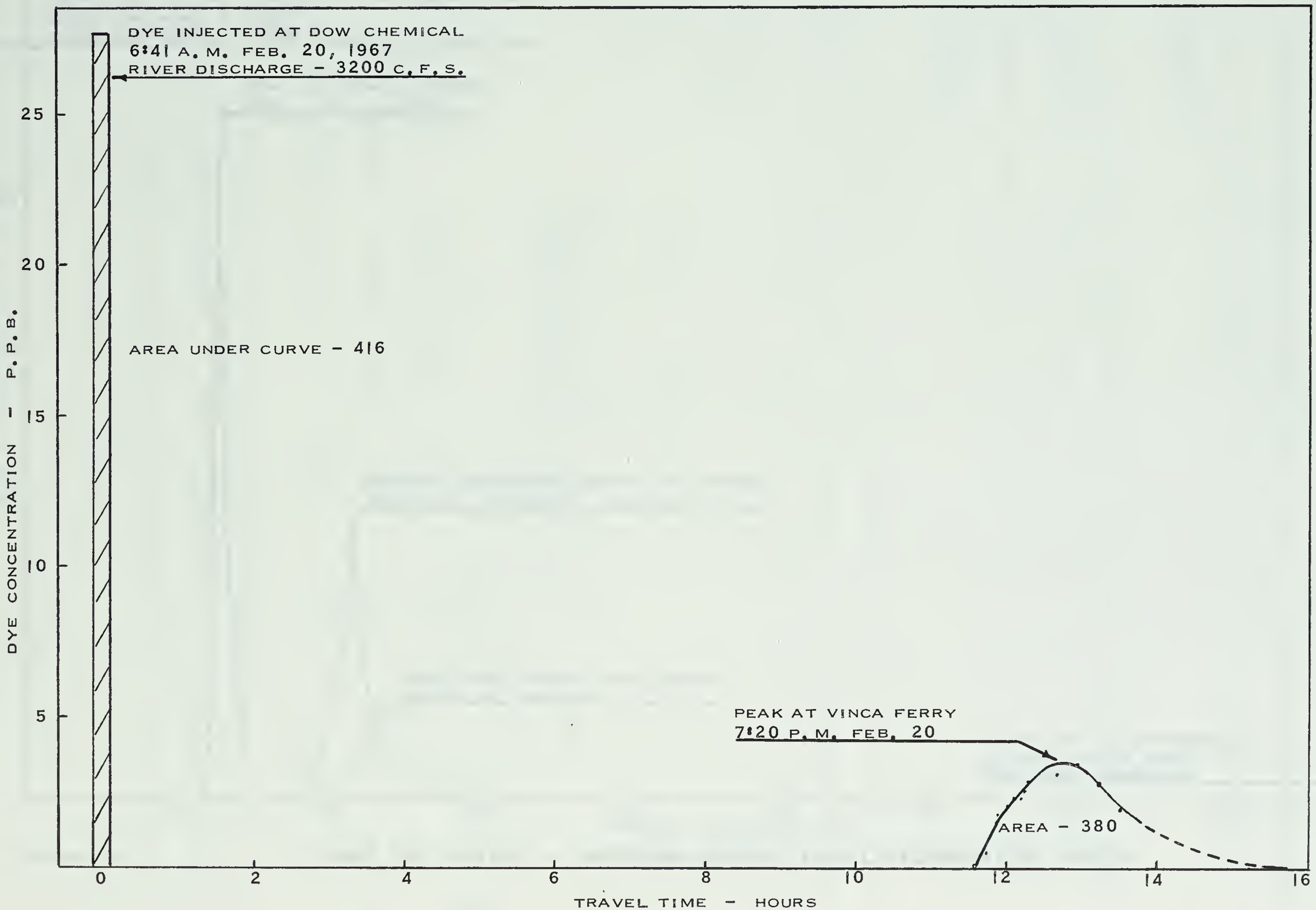

FIGURE 17 TIME OF TRAVEL – DOW CHEMICAL OUTFALL TO VINCA FERRY

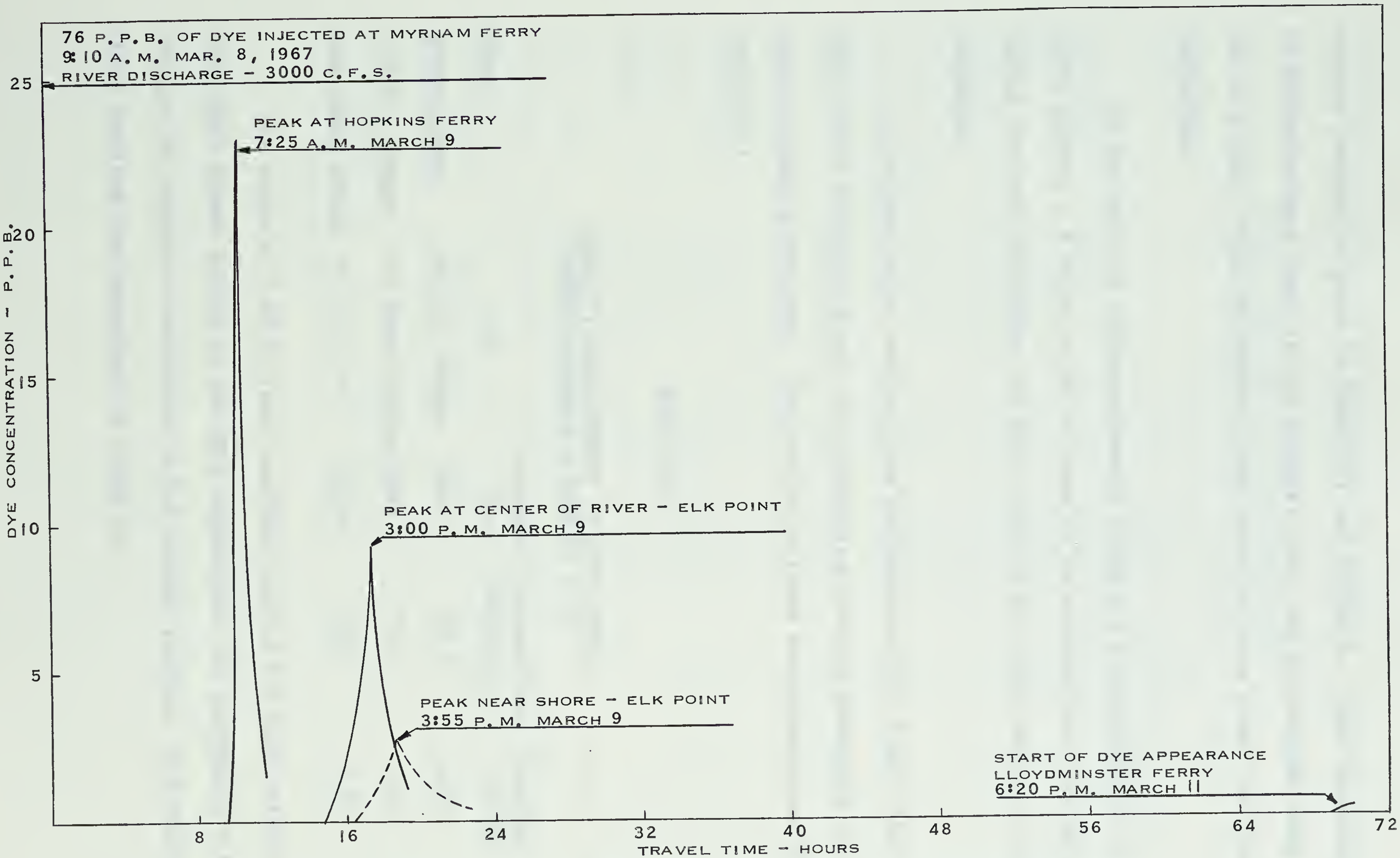

FIGURE 18

TIME OF TRAVEL – MYRNAM FERRY TO LLOYDMINSTER FERRY

various reaches as given in TABLE VII and FIGURE 4. Some inaccuracies in distances were found in the original data, and corrections were made, but no attempt could be made to field check the data given for river elevations.

On the basis of the measurements taken and a consideration of the above points, a K value of 88 was used as an average value for determining the mean velocities for each reach on the river where ice cover prevailed.

In the open water section from the Edmonton City Power Plant to the Main Sewage Treatment Plant, the velocities found by measuring the travel time of oranges were used. The results of these measurements are given in TABLE VIII.

TABLE VIII

VELOCITY MEASUREMENTS IN OPEN WATER
RIVER DISCHARGE = 3080 C. F. S.

From	To	Distance ft.	Elapsed Time minutes	Velocity ft/sec	Average Velocity ft/sec
Power Plant	105 St. Bridge	4690	39.5	1.98	
105 St. Bridge	Low Level bridge	7400	70	1.76	1.86
Low level bridge	M. S. T. P.	15110	125	2.02	

The value of 1.86 ft./sec. was then used as the mean velocity from the 105th Street bridge to the City Lagoons and the conveyance value of 88 used to calculate velocities in ice covered reaches. The velocities thus obtained are summarized in TABLE IX.

TABLE IX

TRAVEL TIMES FOR AN APPROXIMATE RIVER DISCHARGE OF 3000 C. F. S.

From	To	Distance Miles	Mean Slope ft./ft.	Mean Velocity ft./sec.	Time Hours	Time Days	Total Time Days
*105th St.	MSTP	5.65	.000287	1.86	4.45	0.19	0.19
*MSTP	Lagoons	10.55	.000287	1.86	8.31	0.35	0.54
Lagoons	Ft.Sask.Br	8.61	.000378	1.71	7.38	0.31	0.85
Ft.Sask Bridge	Sherritt	2.69	.000331	1.60	2.46	0.10	0.95
Sherritt Gordon	Vinca	13.92	.000331	1.60	12.75	0.53	1.48
Vinca	Waskatenau	17.62	.000505	1.98	13.05	0.54	2.02
Waskatenau	Duvernay	65.04	.000380	1.72	55.5	2.31	4.33
Duvernay	Myrnam	21.95	.000224	1.32	24.4	1.02	5.35
Myrnam	Hopkins	9.68	.000235	1.35	10.51	0.44	5.79
Hopkins	Elk Point	6.30	.000181	1.18	7.83	0.33	6.12
Elk Point	Lindbergh	12.40	.000535	2.04	8.91	0.37	6.49
Lindbergh	Lloyd Fy.	37.96	.000214	1.29	43.1	1.80	8.29
Lloyd Ferry	N. B'ford	98	.00020	1.22	118	4.9	13.2
N.Battleford	Pr.Albert	164	.00017	1.14	211	8.8	22.0
Total		474		1.32			

*Open water

While the data for the determination of the above velocities are limited, it is felt that the calculations have provided a reasonable guide to travel times which might be expected in the river. It must be noted however, that the velocities given are valid only for river discharges close to 3000 c. f. s. and for steady state conditions. A sudden change in measured discharge, immediately before or shortly after the start of a velocity run such as the ones conducted, would produce a wave having a velocity different from the mean velocity of the river, and could result in large errors. An approximate calculation of velocities which might be expected at different flows under ice cover is given in APPENDIX B.

2. Bottom Slimes and Sediments

Sampling baskets were initially placed at four locations for this study. TABLE X summarizes the results obtained.

While the amount of data presented in TABLE X is minimal, certain trends are evident. The absence of stonefly nymphs coupled with the large amounts of slimes and sediments found at the Lagoon sampling site is evidence of a fairly heavy degree of pollution. The presence of worms and the increase in slimes and *Sphaerotilus sp.* growth at Vinca Ferry on the January - February run indicates an increasing rate of pollution at this point. The weight of material obtained at the Lagoon site on the February-March run includes the weight of some bottom muds brought up with the basket and is therefore somewhat higher than it should be. A more accurate determination of the weight of organic material obtained on baskets of this type would be obtained by burning the organic materials and thus separating them from inorganic materials. It is felt

TABLE X

BOTTOM SLIME AND SEDEMENT MEASUREMENTS
USING LIMESTONE FILLED SAMPLERS

Location	Date Set	Date Removed	Time in River days	Weight of Slimes gms.	Daily Accumulation gms/day	Comments
105 St.	Dec.16	Jan.18	33	2.4	0.1	2 large stone fly nymphs
Lagoons	Dec.16	Jan.13	28	30.8	1.1	
Vinca	Dec.16	Jan.20	35	3.0	0.1	1 stonefly nymph
Lloyd.	Dec.26	- Basket lost -				
105 St.	Jan.18	Feb.17	30	4.5	0.2	3 stonefly nymphs
Lagoons	Jan.17	Feb.18	32	3.1	-Data invalid - Basket shaken in removal	
Vinca	Jan.20	Feb.20	31	84.7	2.7	8 stonefly nymphs dozens of $\frac{1}{4}$" long worms, considerable <u>Sphaerotilus sp.</u> growth.
105 St.	Feb.17	Mar.3	14	3.8	0.3	
Lagoons	Feb.18	Mar.3	13	201.2	15.5	Considerable bottom mud brought up with basket.
Vinca	Feb.20	Mar.5	13	10.2	0.8	3 stonefly nymphs, <u>Sphaerotilus sp.</u> growth on wires.

that this procedure would be desirable in future testing.

Visual observations of slime growths and sediment build up in the river in winter time indicated that the river gravel could easily develop one sixteenth of an inch of slime and that sludges could build up between the stones to a depth of one half an inch or more. On the basis of the results obtained, and by making some very approximate assumptions an idea of the slime build up over the total river bottom area can be calculated. The assumptions are that:

(i) the slime and sludge moisture content is approximately 90%;

(ii) the slime density is equal to that of water; and that,

(iii) the slime build up is uniformly distributed and increases at the steady rate of 2 grams per day on the baskets.

A rough measurement of the surface area of the stones in the samplers provided a figure of 3 square feet. From this measurement the weight rate of slime build up is:

$$2 \text{ gms.} / 3 \text{ft.}^2/\text{day}$$

and the wet volume build up is:

$$\frac{2}{3} \times 10 = 6.67 \text{ cm.}^3/\text{day}/\text{ft.}^2$$

or a depth of

$$6.67 \times 0.00108 = 7.2 \times 10^{-3} \text{ cm/day}$$

For a three month period, this would give a total depth of $7.2 \times 10^{-3} \times 90 = 0.65$ cm. or approximately one quarter of an inch of slimes and sludges. Bearing in mind the very approximate nature of this calculation, the results are very similar to those actually observed.

3. B. O. D. and C. O. D. Loadings to the River

As mentioned in CHAPTER IV - 1, samples were collected from each of the waste water effluents to the river, as the slug of water under study, in the river, passed by. B. O. D. and C. O. D. determinations were made on each of these effluents for the December run. A summary of these values is given in TABLE XI.

TABLE XI

SUMMARY OF WASTE WATER LOADINGS TO THE RIVER DECEMBER 16, 1966.

	5 day 20°C B. O. D. lb./day	C. O. D. lb./day	Calculated river values 5 day 20°C B. O. D. mg./l	C. O. D. mg./l
Sewage Treatment Plants	46180	92450	3.34	6.7
Industrial plants	22640	66330	1.63	4.8
Total	68820	158280	4.97	11.5
Values in river at 105 St. bridge			0.7	0.5
Total to be expected in river			5.7	12.0
Actual values found in river at lagoons			6.3	24.5

The results of this survey indicate that the 5 day 20°C B. O. D. found in the river at the lagoon site is a reasonably accurate reflection of the total B. O. D. loading to the river. The C. O. D. values however, show no agreement. This is likely due, as discussed in CHAPTER IV - 6, to the possibility of the types of gross error which may be found in C. O. D. determinations of dilute samples.

Another facet of interest is the relationship between B. O. D. and

C. O. D. values obtained for various effluents, as summarized in TABLE XII.

TABLE XII

C. O. D. TO B. O. D. RATIOS FOR VARIOUS WASTES

	C. O. D. / B. O. D.
Domestic Sewage - primary treatment only	1.5
Domestic Sewage - primary and secondary treatment	2.0
Industrial plant effluents - no treatment	1.8-5.2
Industrial plant effluents - short detention ponding	1.2-1.3

These results indicate that ponding of industrial effluents reduces C. O. D. values in greater proportion than the reduction in B. O. D. and that additional treatment of municipal wastes has a lesser effect on C. O. D. than on B. O. D.

The sampling of waste water effluents to the river was discontinued after this first run, for the following reasons:

(i) Effluent samples were being collected monthly by the Alberta Department of Public Health and these results were available for use.

(ii) The results from this run as well as those supplied by the Alberta Department of Public Health confirmed that the B. O. D. calculated for the river and the B. O. D. measured at the Lagoon site was in fairly close agreement.

(iii) An accurate measure of flow was not available for three industrial plants and estimated values had to be used.

4. Bio-oxidation Relationships

In this study, four runs were made down the river. Determinations of the B. O. D., dissolved oxygen, and C. O. D. were made from river samples taken at suitable sampling points. A summary of three of these runs is graphically illustrated in FIGURE 19.

A tabular summary of the B. O. D. and D. O. values of the four runs as well as data supplied by the Sanitary Engineering Division of the Alberta Department of Public Health and by the City of North Battleford is given in FIGURE C1 of APPENDIX C.

The data in FIGURE C1 is arranged so that, for each sample, the B. O. D. is given above the D. O. The sampling points are listed in a manner such, that by following lines parallel to the dashed sloped lines on the figure, the values of B. O. D. and D. O. in the river for a particular slug of water may be determined for a river discharge of approximately 3000 c. f. s. A mean of all winter values obtained is listed on the extreme right hand side of FIGURE C1 and graphically depicted, along with 1961-62 and 1964 winter means, in FIGURE 20. FIGURES C2 to C7 in APPENDIX C show D. O. deficit and B. O. D. curves, compiled from the data in FIGURE C1 which fitted the time of travel lines drawn.

Data from the Alberta Department of Public Health for March, April and May, 1966 are included on the left hand side of figure C1. An examination of these data shows that B. O. D. values at Fort Saskatchewan increased very markedly starting on March 30, with a corresponding increase in B. O. D. downstream a few days later. At this time, the river discharge also began to increase. From information supplied by the City of Edmonton,

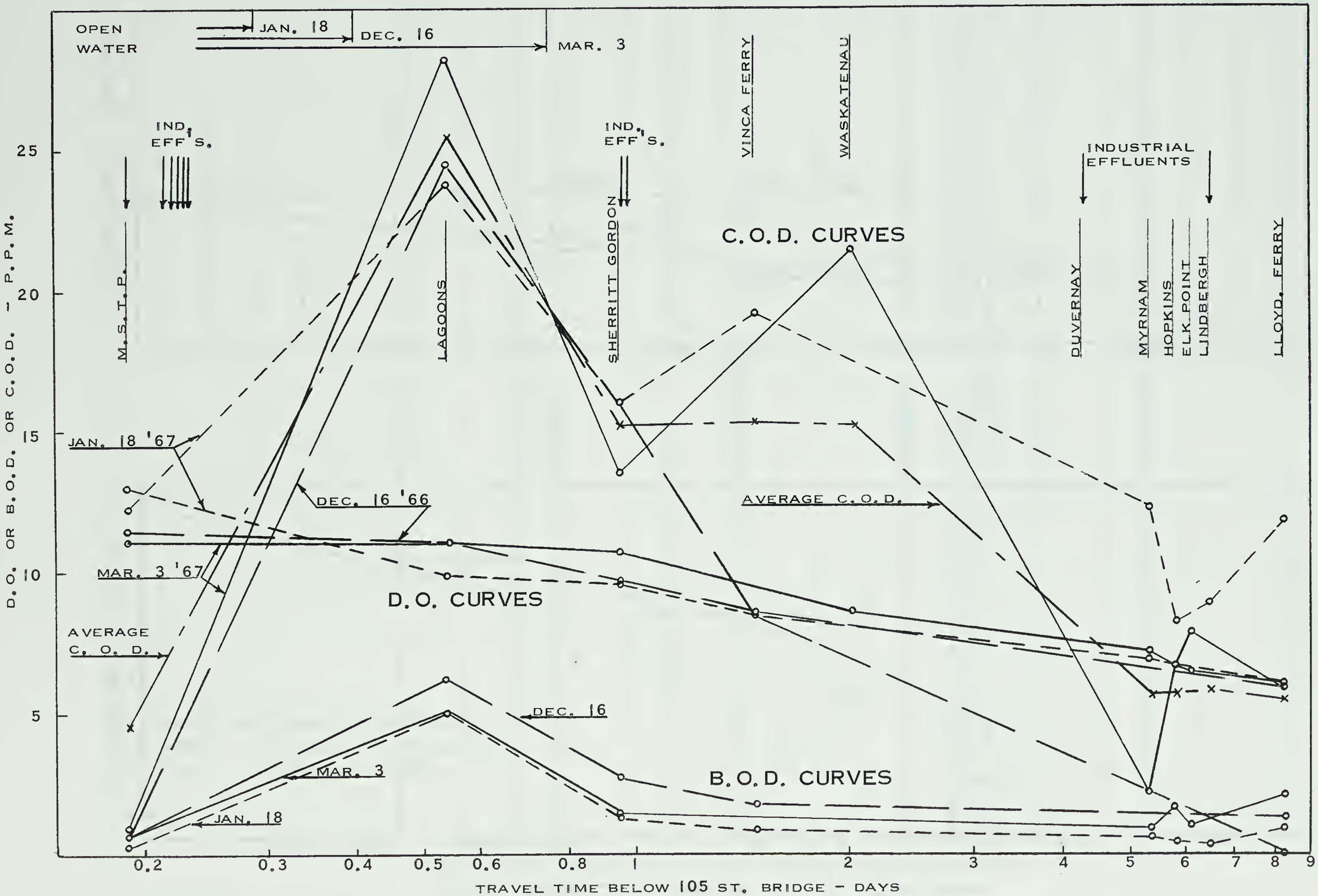

FIGURE 19 B.O.D., D.O. AND C.O.D. CURVES – NORTH SASKATCHEWAN RIVER

APPROXIMATE DISCHARGE - 3000 C.F.S.

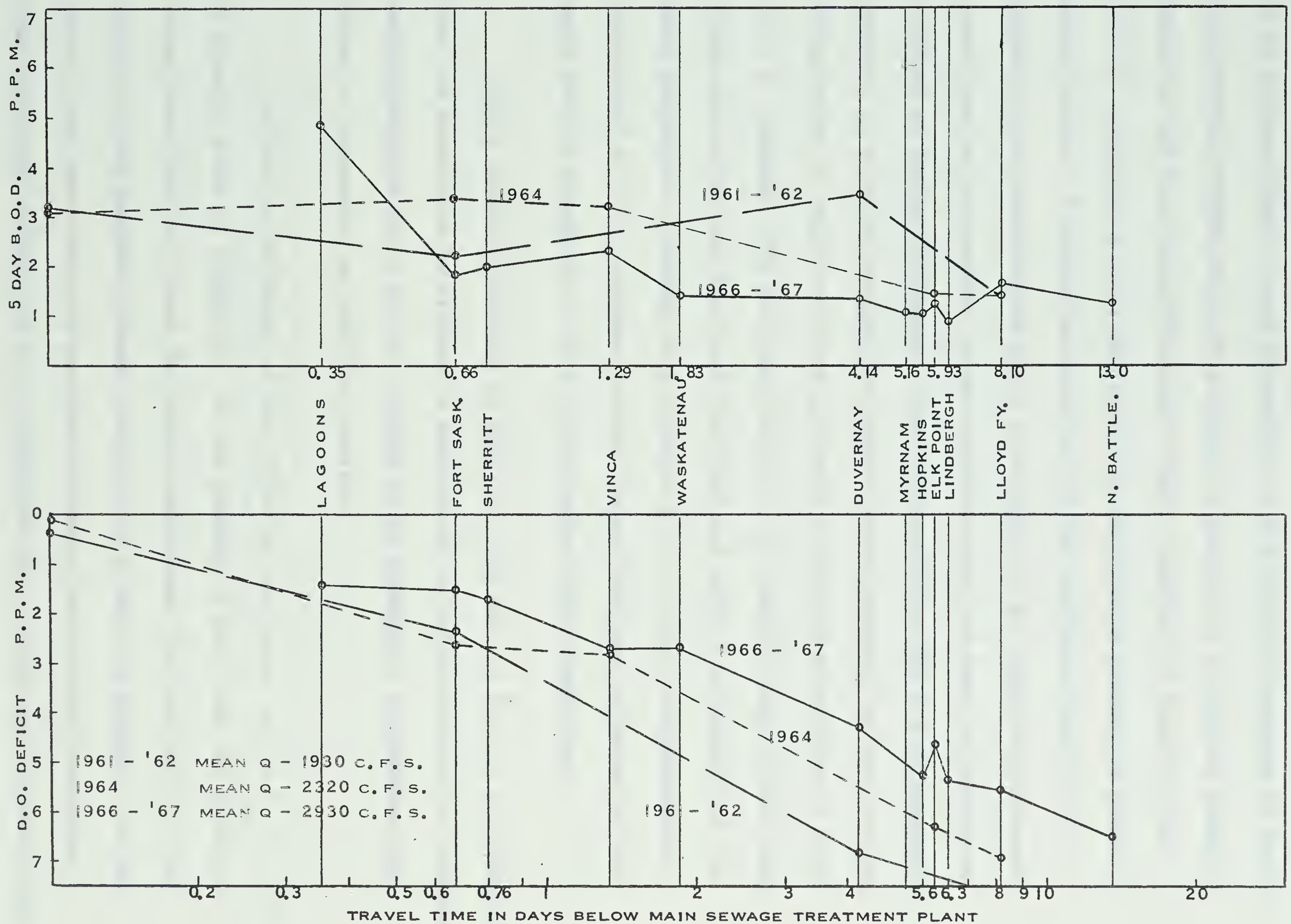

FIGURE 20

D. O. DEFICIT AND B. O. D. CURVES

MEAN VALUES FOR ICE COVER PERIODS

it is apparent that a large percentage of the B. O. D. increase at Fort Saskatchewan between March 29 and April 2 was due to a high raw sewage bypass at the Main Sewage Treatment Plant. However, by April 3, the B. O. D. loadings to the river from this source were reduced to normal winter levels. A logical explanation for the continued high B. O. D. values in the river between April 4 and April 6 is that the increased river flow had scoured the bottom deposits which had been collecting and building up during the winter. This increased flow and its corresponding increase in velocity brought the organic bottom material up into the main stream where it could be picked up during sampling and thus give a high B. O. D. reading. The fact that the B. O. D. remained high further downstream was due to the fact that the river was still ice covered and the water temperature probably very close to $0^{o}C$. At this low temperature, the rate of B. O. D. decrease is very low and this was reflected in the small rate of change in B. O. D. as the water moved downstream.

Spring break-up occurred on April 8, 1966 and the rate of reoxygenation from the atmosphere is evident in the high D. O. values obtained at Duvernay and Lindbergh on May 9 and 10. FIGURE C8 in APPENDIX C illustrates the effect of reaeration on the D. O. deficit.

A further illustration of the effect of open water on the D. O. deficit is clearly shown in FIGURE 19. On the January 18 run, when the river was frozen over from the Clover Bar bridge downstream, the rate of D. O. depletion is the greatest between the M. S. T. P. and the lagoons. On the March 3 run, when the river was open to nearly twelve miles downstream from Clover Bar bridge, the D. O. depletion rate is the least between these

points. It should also be noted that, as the open water channel increased in length, the width of open water also increased as the ice shelves projecting from each bank melted. These varying rates of D. O. depletion, did not appear to have any effect on the rate of B. O. D. uptake in the area. However, it must be borne in mind that the curves plotted in FIGURES 19, 20 and C2 to C8 reflect only the values found at the sampling points. Straight line rates of change do not actually take place, particularly between the M. S. T. P. and the Sherritt Gordon intake. It would have been desirable in this study to have obtained B. O. D., C. O. D. and D. O. values in the river between the M. S. T. P. and the lagoon site, in order to provide a better picture of the true river conditions. This was not feasible, not only because of the difficulty of getting down to the river in the area but also because of incomplete mixing in this region. The lagoon site is probably the most easily accessible, closest site to the city at which complete mixing of wastes has taken place in the river.

Between the lagoon site and Sherritt Gordon intake there is a rapid decrease of both B. O. D. and C. O. D. with very little depletion of dissolved oxygen. The evidence obtained from the sampling basket program indicates that this must be due to settling out of a large portion of the organic load combined with adsorption of this load by the stony river bottom.

Of the 68820 lbs. of B. O. D. loading to the river listed in TABLE XI, approximately 50000 lbs. is from effluents which have passed through settling ponds or tanks. The balance of the wastes receive no treatment before they are discharged to the river and undoubtedly contain some oxygen

demanding material which can settle to the river bottom. Between the Lagoon site and Vinca Ferry, however, a minimum of 70% to 80% of the 5 day B. O. D. is removed from the river with very little D. O. depletion (FIGURE 19). It is postulated, therefore, that the decrease in B. O. D. occurs mainly through adsorption.

It is further felt that while the bottom sediments are exerting virtually no demand on the dissolved oxygen in the river, a zone of anaerobic biological activity may be present on the river bottom. It is possible that a thin zone of low velocity flow may exist on the bottom of the river, which has an oxygen tension low enough to be non-toxic to anaerobes and facultative anaerobes, and thus allow these organisms to utilize chemically combined oxygen in the breakdown of organic material.

From the Sherritt Gordon intake to Vinca Ferry it is clear that the rate of B. O. D. decrease is beginning to stabilize as is the rate of oxygen depletion. Because of the addition of industrial effluents below the Sherritt Gordon intake, however, C. O. D. values tend to increase slightly.

From Vinca Ferry to Lloydminster Ferry, the rates of D. O. depletion and B. O. D. decrease shown on FIGURE 19 are quite consistent. An examination of FIGURES C2 to C7, however, shows that while the rate of D. O. depletion is relatively consistent in this region, B. O. D. reduction rates are variable. FIGURE 19 demonstrates that the rates of C. O. D. decrease in this area are also variable.

Certain rate trends, however, are clearly depicted on FIGURE 19 in

the reach from Vinca Ferry to Lloydminster Ferry. The rate of C. O. D. decrease is greater than the rate of B. O. D. reduction, with the D. O. depletion rate lying somewhere in between. It is felt that this provides an indication of a slower rate of continuing adsorption. The increased rate of oxygen depletion is likely due to a lag phase in the oxygen demand and the suspended solids, probably in a colloidal form, are beginning to exert an oxygen demand from the Sherritt Gordon intake downstream. It is also clearly evident in this region, that the rates of oxygen depletion and of B. O. D. removal are quite different.

As discussed earlier, the prime purpose of this study was an attempt to formulate the bio-oxidation relationships occurring in the river under ice cover. From the data obtained, it is evident that many factors are influencing these relationships, particularly between the M. S. T. P. and Vinca Ferry. It is felt therefore, that in the absence of further data an attempted formulation would be misleading. In the region from Vinca Ferry to Lloydminster however, an approximation of D. O. depletion may be made.

From the runs illustrated in FIGURES C2 to C7, average values of the D. O. deficit for Vinca Ferry and Elk Point are 2.63 mg/l and 4.96 mg/l respectively. In order to determine an equation which may be of practical value, zero time is taken at the M. S. T. P. and the D. O. deficits are taken as the deficit below the value of D. O. found at the 105th Street bridge. The form of equation for a straight line on semi-log paper is:

$$D = D_o + K \log \frac{t2}{t1} \qquad (16)$$

where D is the D. O. deficit (mg./l.) at time t_2 days below the M. S. T. P.,

D_o represents the deficit at Vinca Ferry as defined above (mg./l.) and t_1 is the travel time in days from the M. S. T. P. to Vinca Ferry.

Thus, for the values previously given and for travel times from TABLE IX, substituting in equation (16):

$$4.96 = 2.63 + K \log \frac{5.93}{1.29}$$

$$2.33 = K \log 4.6$$

$$K = \frac{2.33}{0.662} = 3.52$$

Equation (16) then becomes:

$$D = D_o + 3.52 \log \frac{t_2}{t_1}$$

However, as this is based on a specific time at Vinca Ferry a value of 1.29 must be substituted for t_1 and the equation then becomes:

$$D = D_o + 3.52 \log t_2 - 0.39 \qquad (17)$$

Using this equation, curves are plotted on FIGURES C2 to C8. From these plots, values obtained for the furthest point downstream are, with one exception, within 15% of actual values found. The one exception, on the run of January 19, is in error by 23.5%.

An attempt was made to fit equation (17) to the data from previous years plotted on FIGURE 20. Results however, did not agree. This is due to the fact that equation (17) is based on an approximate flow of 3000 c. f. s. with the velocities corresponding to this flow. The average flows of 1930 c. f. s. and 2320 c. f. s. given for the plots in FIGURE 20 would result in lower river velocities and would have the effect of changing the

value of the constants in equation (17). The constants in this equation would also be changed by the higher B. O. D. values found in 1961-62 and 1964. It must therefore be recognized that equation (17) is valid for conditions similar to those which existed in this study program. Future studies of this type will provide a broader range of data for the varying conditions found in the river, and will possibly allow an equation to be formulated which will include all of the parameters which affect the bio-oxidation rates in the river.

CHAPTER VI

SUMMARY AND CONCLUSIONS

1. Velocity Measurements

Values for mean river velocities can be determined satisfactorily with the use of a photofluorometer and Rhodamine B dye. An average conveyance factor (K) of 88, may be used, with reasonable accuracy in the Manning equation, to determine river velocities under ice cover for a river discharge of 3000 c. f. s. Values of mean velocity in the North Saskatchewan river under ice cover in the study area were found to range from 1.14 to 2.04 f. p. s. for an approximate river discharge of 3000 c. f. s. (TABLE IX).

2. Sludge and Slime Deposits

A calculated rate of build up of slimes and sludges on the river bottom of approximately 2/3 of a gram per square foot per day agrees favorably with visual observations of these deposits in the river. Bottom deposits appear to increase progressively downstream during the winter and are scoured during high spring flows, producing a high B. O. D. in the river at this time.

The absence of stonefly nymphs in the river at the Lagoon sampling site may be taken as an indicator of fairly heavy pollutional loadings.

3. B. O. D. and C. O. D. Loadings to the River

A knowledge of the individual rate of flow and B. O. D. of each effluent to the river may be used to calculate an expected river B. O. D. with reasonable accuracy (TABLE XI). No correlation between river C. O. D. and C. O. D. loadings appears to be possible.

Secondary sewage treatment of municipal wastes produces a greater reduction of B. O. D. than C. O. D., whereas ponding of industrial effluents appears to have the opposite effect (TABLE XII).

4. Bio-oxidation Relationships

From an examination of FIGURES 19, 20 and C2 to C7, the following events are postulated to occur in the river, during the winter period of low flow, as it flows downstream from Edmonton.

1. Oxygen demanding materials from waste effluents are adsorbed on to the rocks and bed of the river with a certain amount of this material actually settling to the river bottom.

2. These bottom materials exert essentially no oxygen demand on the dissolved oxygen in the river. This occurs because of; (a) greatly reduced rates of biological oxidation at near freezing temperatures, and/or (b) anaerobic fermentation of bottom (benthal) deposits in a thin zone of low oxygen tension and low velocity near the river bed.

3. After approximately one day in the river, the oxygen demanding materials in suspension begin to exert an increased rate of dissolved oxygen demand. In the region, from Vinca Ferry downstream, an equation relating dissolved oxygen deficit to time was determined for velocities corresponding

to a river discharge of 3000 c. f. s. This equation is in the form:

$$D = D_o + 3.52 \log t_2 - 0.39 \qquad (17)$$

in which D is the D. O. deficit at time t_2 days, below the D. O. found at the 105th Street bridge (mg./l.): D_o is the D. O. deficit at Vinca Ferry (mg./l.) and t_2 represents the travel time in days below the Main Sewage Treatment Plant. The use of this equation with the data obtained in this study produced results, with one exception, within 15% of actual values found downstream. The error in the one exception was 23.5%. A comparison of the results obtained using equation (17) and data from previous years showed no correlation. Equation (17) was formulated from specific data under specific conditions of loading and river flow and velocity. This equation therefore should be used with care where conditions vary appreciably from those which existed in this study.

4. In spring, increased velocities in the river due to higher rates of flow, scour the bottom deposits which have accumulated during the winter, and bring them into suspension. Because of the low water temperature, however, biological activity is limited and severe oxygen depletion does not occur within the study area.

5. In the region just downstream from Edmonton, river reaeration from the atmosphere is occurring. The variation in length and width of ice free channel clearly affects the dissolved oxygen levels found in this area (FIGURE 19).

During open water conditions a sag develops in the dissolved oxygen deficit curve about one day's travel time below Edmonton (FIGURE C8). Atmospheric reaeration relieves this deficit and generally brings D. O. levels back to normal within three or four days.

CHAPTER VII

RECOMMENDATIONS

1. Measurements of Mean Velocity

The use of a more sensitive photo-fluorometer, enabling lower dye concentrations to be measured, would allow longer dye runs to be made and thus cut down on the handling of dyes.

The rapid reduction in Rhodamine B concentration (FIGURES 17 & 18) may be due to adsorption of the dye by suspended materials or may be due to not pre-mixing the dye in water. It is suggested that Pontacyl Brilliant Pink B dye, be tried in future tests, as it is not adsorbed by suspended material.

Dye should be injected in the main stream of the river to provide more accurate velocity measurements.

It is suggested that some dye tests be conducted in open water so that observations and measurements of the dispersion characteristics of relatively straight and curved channels can be made. This would also provide a measure of the lateral and longitudinal dye wave profile and the effect of mixing in the river.

A more extensive velocity survey at different river discharges would be beneficial for studies of this type and would undoubtedly help to provide a clearer picture of the settlement and adsorption of organic materials

in the river.

2. Bottom Sampling

The use of a rectangular, flat sampling basket is recommended (CHAPTER IV - 3).

A fine mesh screen suspended vertically in the river, would be a useful adjunct to this type of survey in that it would provide some indication of the amount and rates of change of suspended material in the river.

For lowering baskets into the river under ice, a rope which will sink in water should be used. (CHAPTER IV - 3)

In determining the weight of organic material collected on these baskets it is suggested that, after weighing the total dry material obtained, the organic material be burned off and the residue weighed. This would provide a more accurate estimate of biologically degradable material present.

3. Bio-oxidation Factors

An accurate portable dissolved oxygen meter would be an invaluable aid in this type of study.

A vertical dissolved oxygen profile, taken in the river at various points, would establish whether a zone of low oxygen tension is, in fact, present at the bottom of the river.

A microbiological examination of bottom materials, would evaluate

the possibility of there being an anaerobic or facultatively anaerobic zone on the river bottom.

Accurate measurement of the flow of industrial effluents to the river along with their B. O. D., C. O. D., and D. O. is recommended. This will not only provide a check on the values of these parameters found in the river but will also assist in the evaluation of river bio-oxidation rates.

4. General Recommendations

A continuance of this study in future is strongly recommended. The use of the preceding suggestions should provide a more rapid and improved assessment of bio-oxidation rates in the river under ice cover. The collection of a broader range of data under more widely varying rates of flow and loading will undoubtedly lead to an accurate formulation of dissolved oxygen depletion and B. O. D. uptake for the whole study area, and will provide a useful tool which may be used to assist in the control of pollution in the North Saskatchewan river under ice cover conditions.

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APPENDIX A

RIVER DISCHARGE DATA

TABLE A1

COMPARATIVE RIVER DISCHARGE VALUES IN C. F. S.

Fed. - From Federal Department of Energy Mines & Resources
City - From City of Edmonton Power Plant

	1966		1967					
Month	Dec.		Jan.		Feb.		Mar.	
Day	City	Fed	City	Fed	City	Fed	City	Fed
1	3500	2790	2500	2780	-	3300	2500	2680
2	3700	2700	2500	2720	3800	2790	3000	3030
3	2800	1960	3000	2630	4000	2720	3000	2800
4	3200	2630	2400	2740	3800	3850	2800	2980
5	2600	1780	1700	2760	3500	3340	3000	3190
6	2400	1580	2600	2790	3500	3320	3200	3120
7	2100	1500	2500	2760	3000	3110	2800	2660
8	2400	1680	2800	2920	3000	3040	2700	2790
9	3000	2510	3000	3170	3000	3100	3000	3210
10	3200	2680	3000	3070	3000	3050	3000	3120
11	3200	2590	2500	2760	3300	3140	3000	3040
12	3200	2570	1500	2540	3000	3140	2800	3070
13	3200	2300	1700	2630	-	3150	2700	2920
14	3000	2350	1700	2750	3000	3040	2500	2590
15	3200	2480	1700	2890	3000	3120	2700	2760
16	3100	2570	1700	3000	3000	3180		
17	3800	2930	2000	3030	3000	3170		
18	3800	3170	-	3240	3200	3190		
19	3800	3320	-	3430	3200	3220		
20	3800	3210	1400	3370	3000	3150		
21	4000	3260	1300	3080	3200	3210		
22	3800	3110	1700	2900	3300	3300		
23	3800	3180	3000	3220	3200	3140		
24	3700	2940	3000	3220	3200	3050		
25	3500	2830	3000	3150	3000	2980		
26	3500	2890	3000	3460	3200	3120		
27	3100	2460	3500	3680	3000	2900		
28	3000	2240	2700	3550	2700	2900		
29	3000	2240	2000	3580				
30	3000	2240	3500	4080				
31	2600	2240	-	4000				

The data given in TABLE A1, indicates the broad variation in river discharge results obtained from these sources. The reasons for this variation are discussed in CHAPTER IV - 7.

Using gauge height data from the City Power Plant and river discharge measurements from the Federal Government, a rating curve was established for the Power Plant for ice cover conditions and low flow. This curve, illustrated in FIGURE A1, was used to obtain an approximate idea of the river discharge at the time of starting the runs down the river.

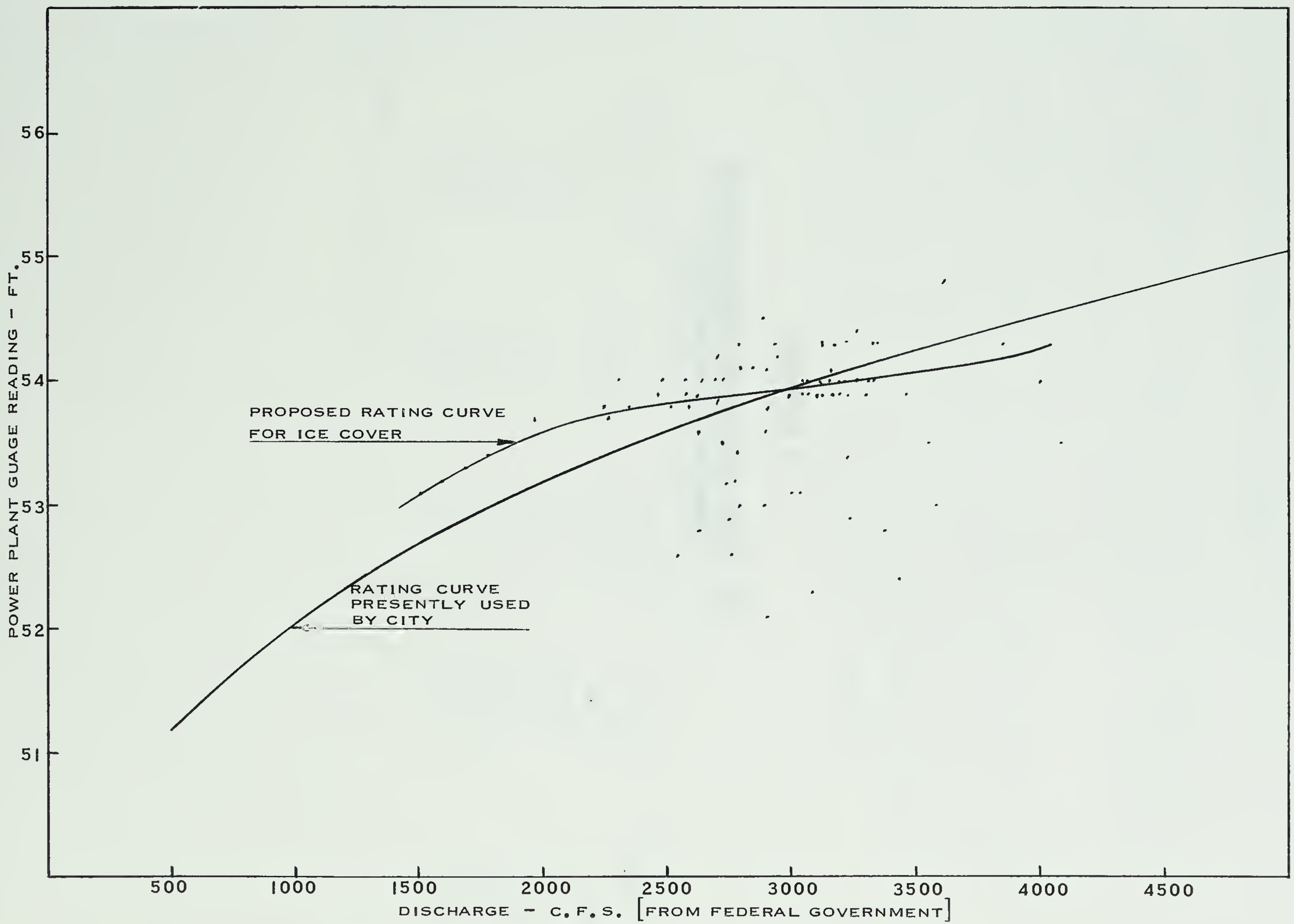


FIGURE A - I STAGE DISCHARGE CURVES AT CITY POWER PLANT

APPENDIX B

ESTIMATED MEAN VELOCITIES UNDER ICE FOR VARIOUS DISCHARGES

APPENDIX B

ESTIMATED MEAN VELOCITIES UNDER ICE COVER FOR VARIOUS DISCHARGES

In this calculation a velocity of 1.5 f. p. s. combined with a discharge of 3000 c. f. s. is used as a starting point. This results in an area of flow of 2000 $ft.^2$

If the river is considered to be 500 feet wide, any small increase or decrease in depth will give an incremental increase in area of the change in depth times 500 feet. On this basis the calculations for change in river velocity were made as illustrated in TABLE B1.

TABLE B1

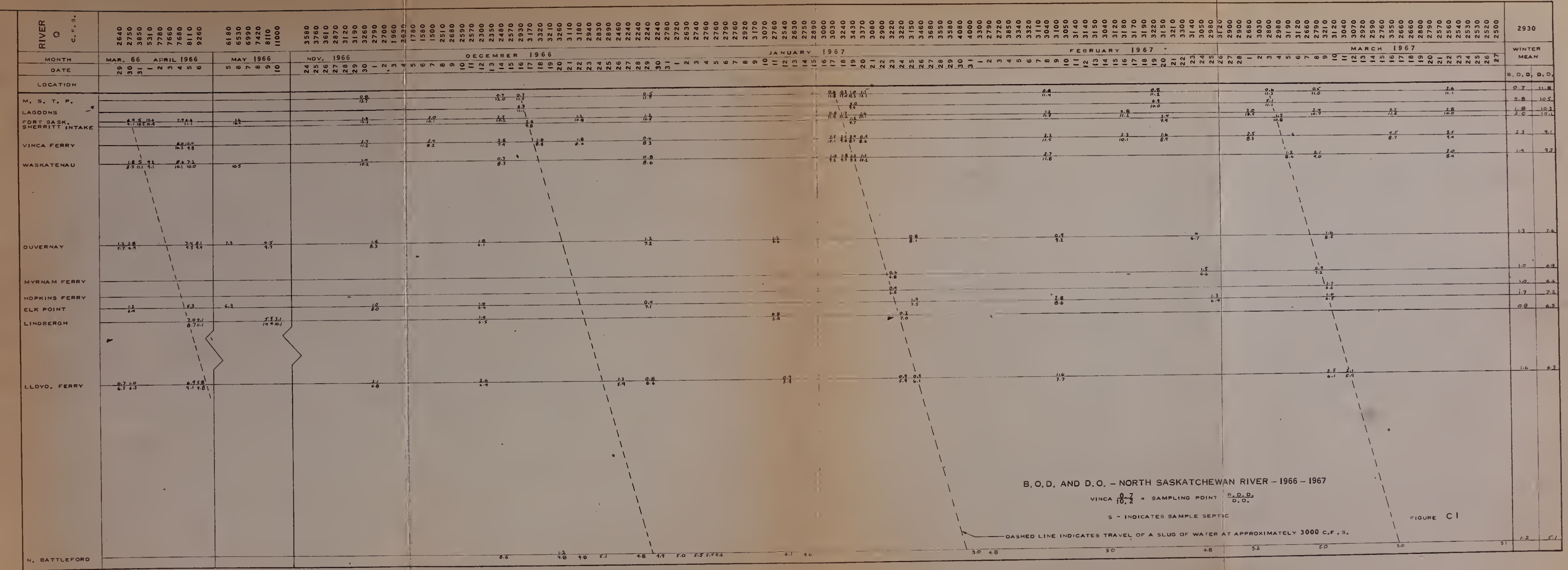
CALCULATED MEAN VELOCITIES FOR VARIOUS DISCHARGES UNDER ICE COVER

c.f.s.	Gauge Height ft.	Increase * in Gauge ft.	Increase in Flow area $ft.^2$	Area of Flow $ft.^2$	Velocity ft./sec.
3000	8.72	-	-	2000	1.5
1500	7.54	-1.18	-590	1410	1.06
2000	8.00	-0.72	-360	1640	1.22
2500	8.35	-0.37	-185	1815	1.38
3500	9.07	0.35	+175	2175	1.61
4000	9.35	0.63	+315	2315	1.73

* From Federal Government Data

APPENDIX C

D. O. AND B. O. D. DATA



B.O.D. AND D.O. – NORTH SASKATCHEWAN RIVER – 1966 – 1967

VINCA $\frac{0.7}{10.2}$ = SAMPLING POINT $\frac{\text{B.O.D.}}{\text{D.O.}}$

S – INDICATES SAMPLE SEPTIC

FIGURE C1

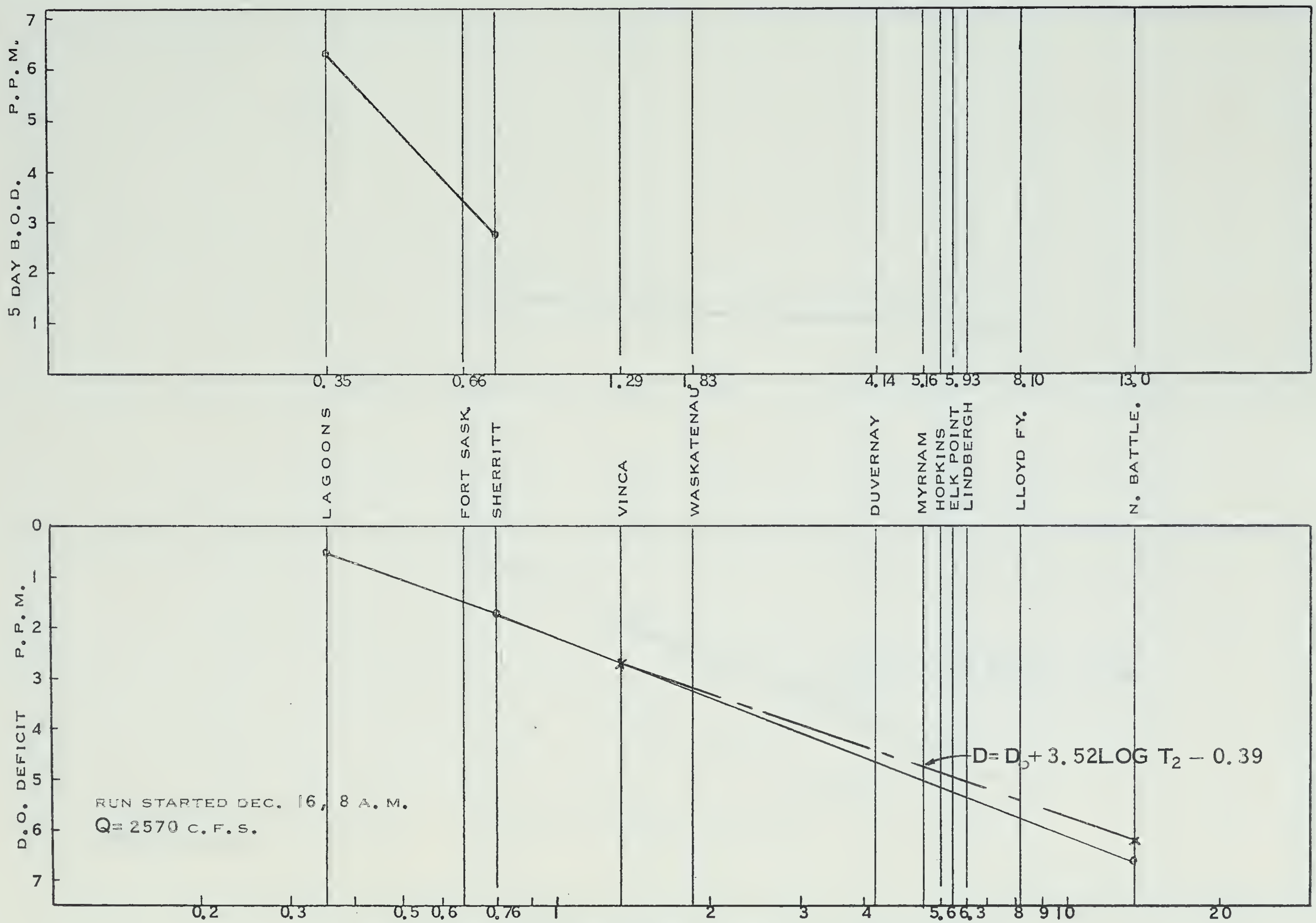


FIGURE C2 D. O. DEFICIT AND B. O. D. CURVES

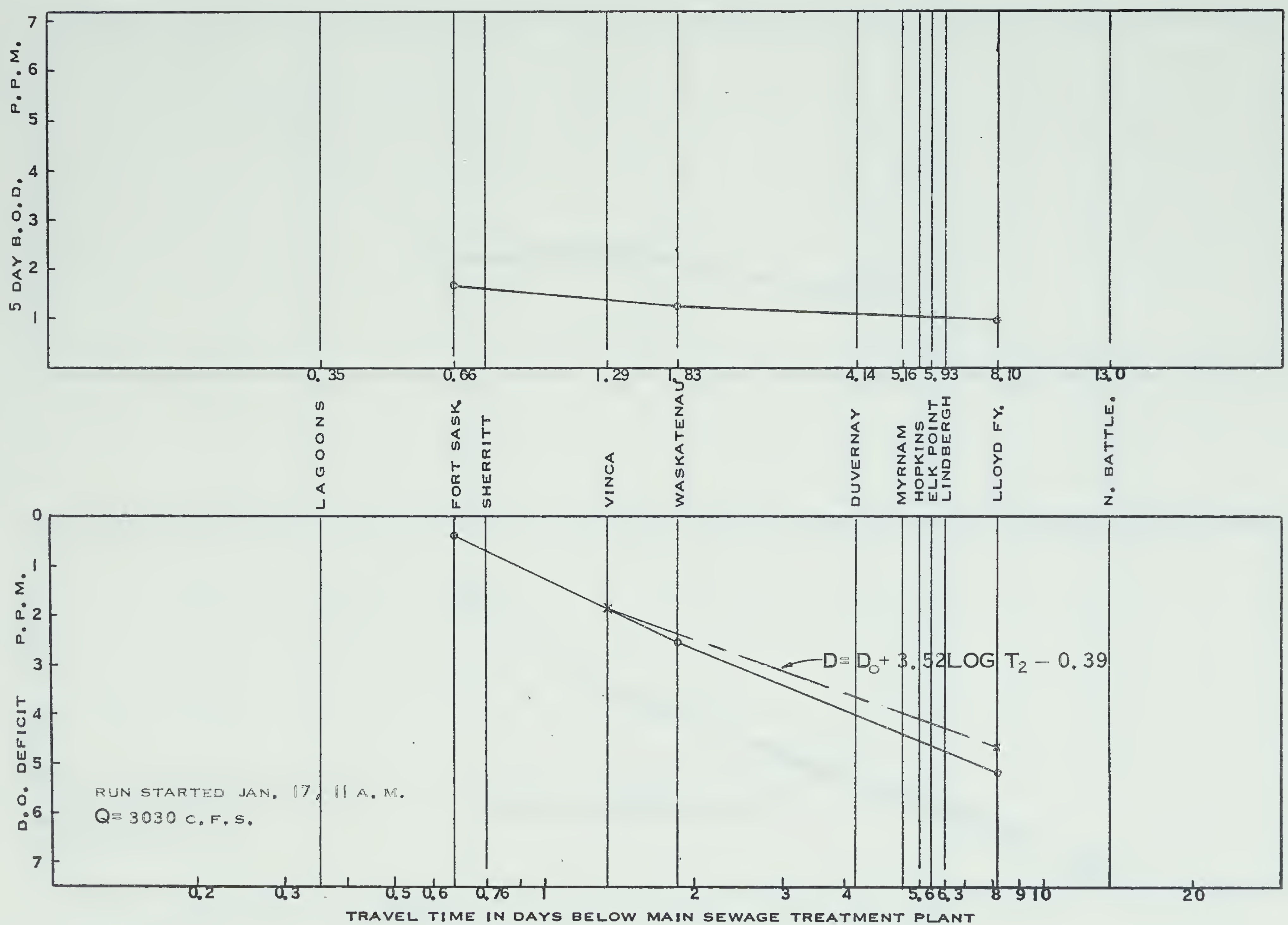


FIGURE C3 D. O. DEFICIT AND B. O. D. CURVES

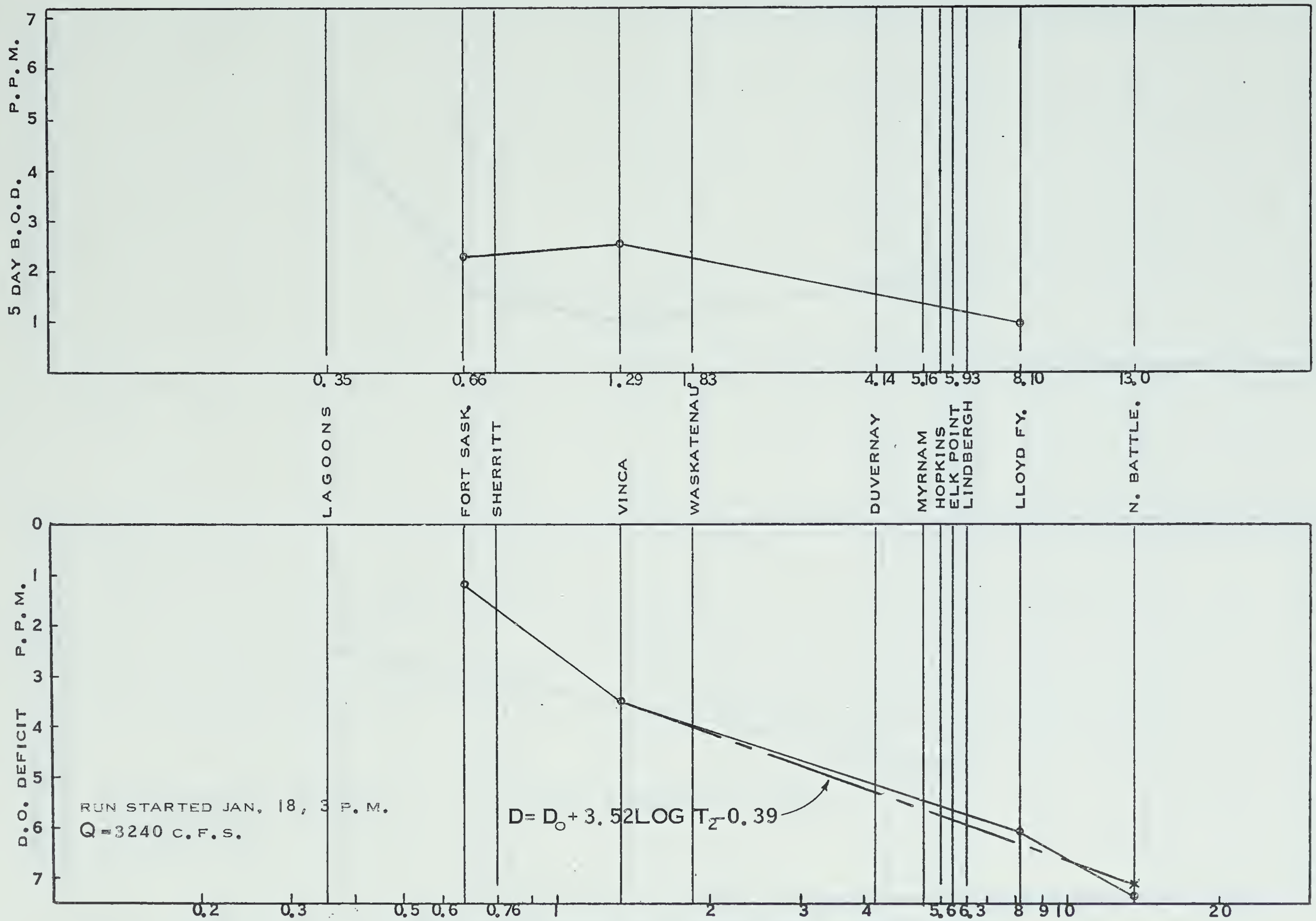


FIGURE C4

D. O. DEFICIT AND B. O. D. CURVES

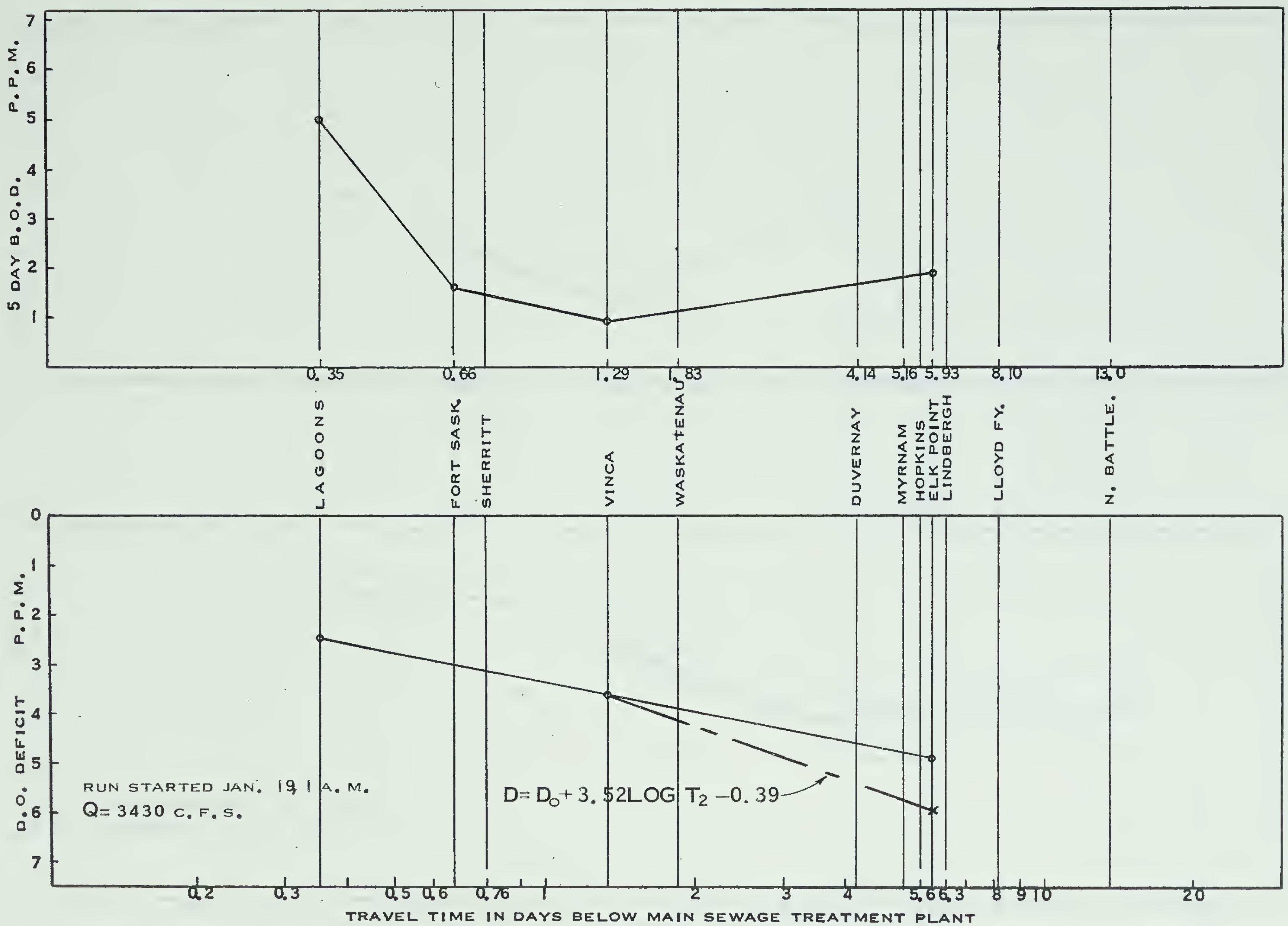


FIGURE C5 D. O. DEFICIT AND B. O. D. CURVES

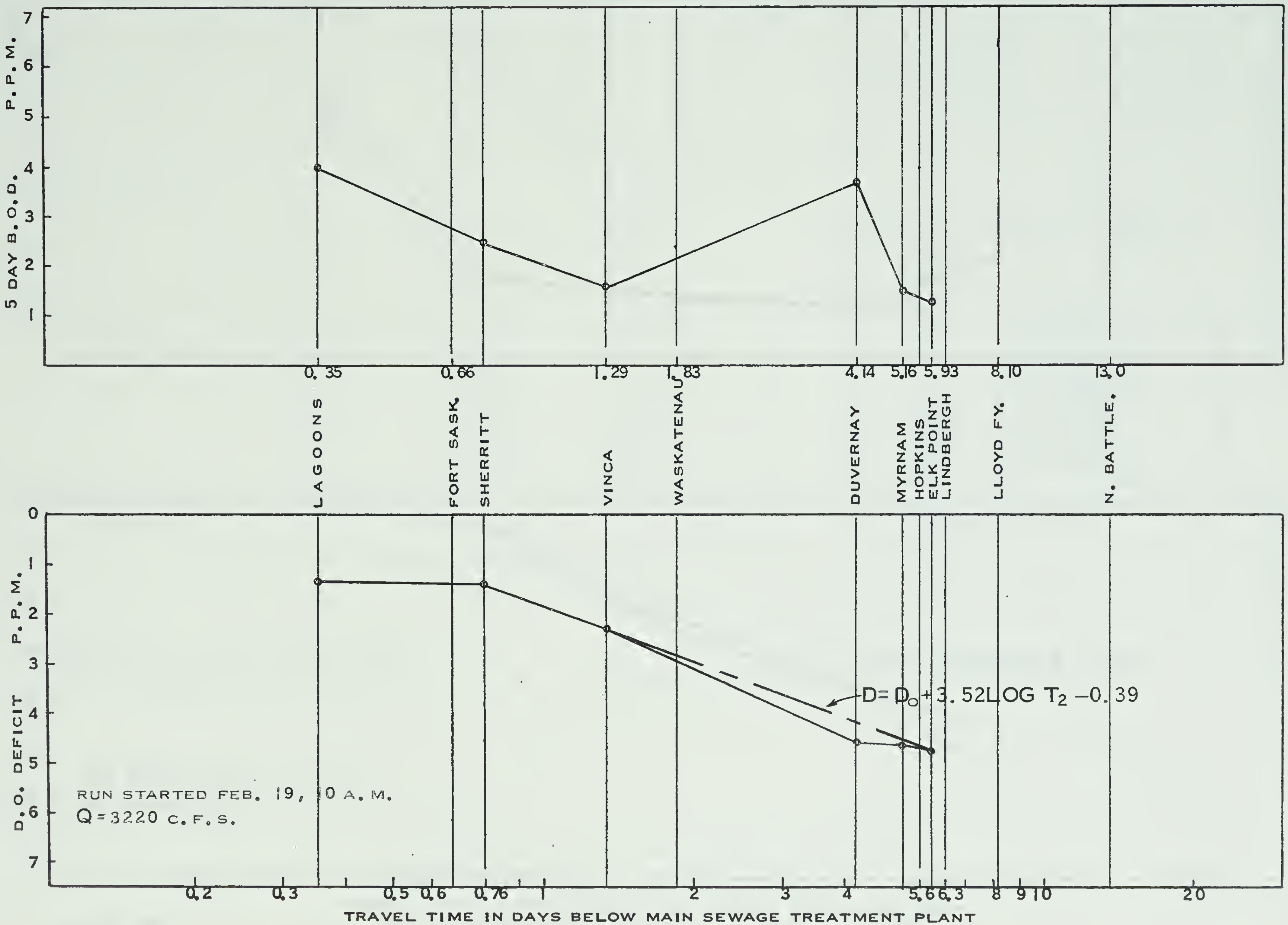


FIGURE C6

D. O. DEFICIT AND B. O. D. CURVES

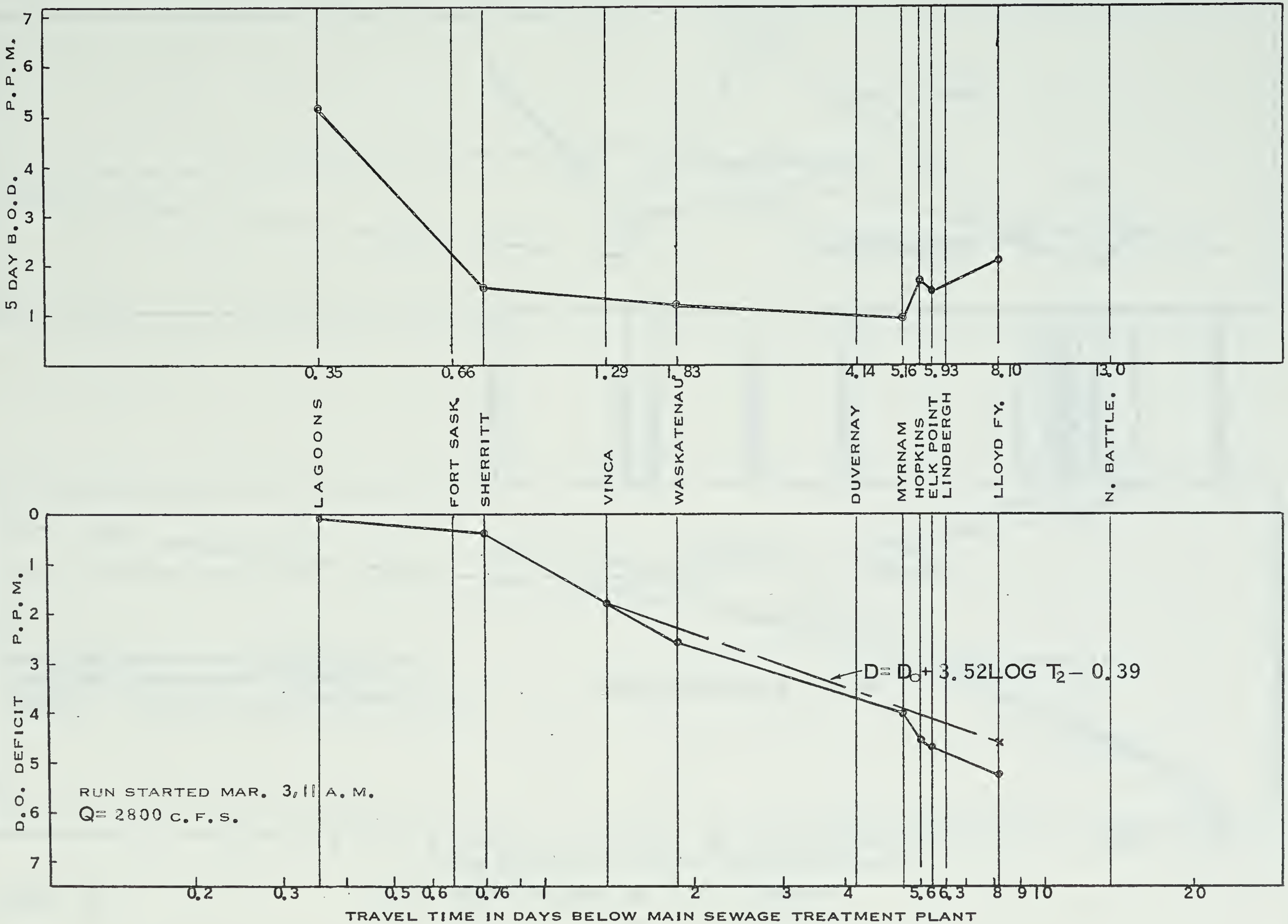


FIGURE C7

D. O. DEFICIT AND B. O. D. CURVES

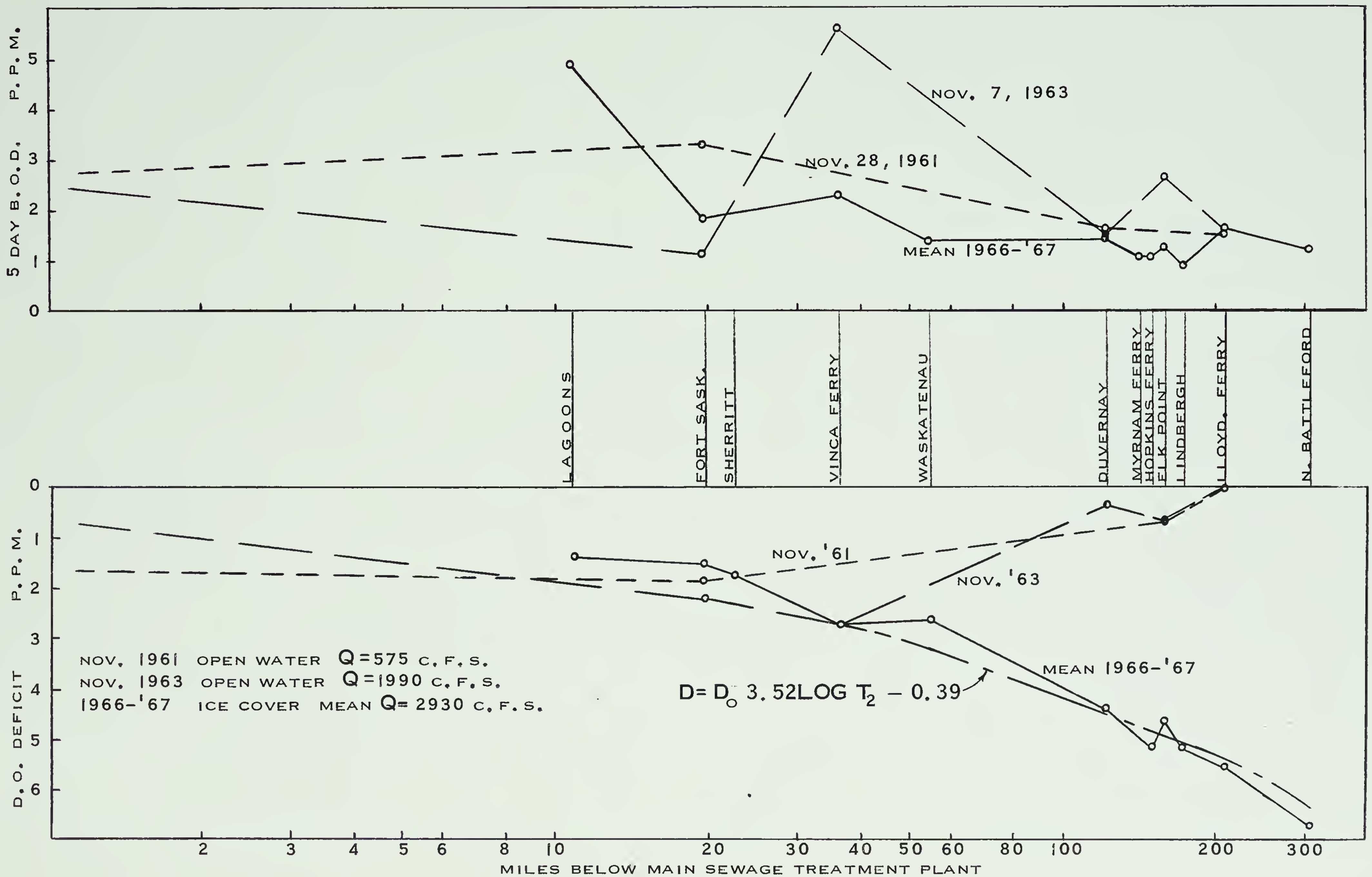


FIGURE C8 D. O. DEFICIT AND B. O. D. CURVES